Zackenberg Basic

The BioBasis programme

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ZERO

ZACKENBERG ECOLOGICAL RESEARCH OPERATIONS

19th Annual Report 2013

GEM

Greenland Ecosystem Monitoring

Aarhus University
DCE – Danish Centre for Environment and Energy

ZACKENBERG ECOLOGICAL RESEARCH OPERATIONS

19th Annual Report 2013

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Zackenberg Ecological Research Operations (ZERO) is together with Nuuk Ecological Research Operations (NERO) operated as a centre without walls with a number of Danish and Greenlandic institutions involved. The two programmes are gathered under the umbrella organization Greenland Ecosystem Monitoring (GEM). The following institutions are involved in ZERO:
Department of Bioscience, Aarhus University: GeoBasis, BioBasis and MarineBasis programmes
Greenland Institute of Natural Resources: MarineBasis programme
Asiaq – Greenland Survey: ClimateBasis programme
University of Copenhagen: GeoBasis programme
Geological Survey of Denmark and Greenland: GlacioBasis programme

The programmes are coordinated by a secretariat at Department of Bioscience, Aarhus University and financed through contributions from:
The Danish Energy Agency
The Environmental Protection Agency
The Government of Greenland
Private foundations
The participating institutions

Contents

Summary for policy makers

Lillian Magelund Jensen, Torben Røjle Christensen and Niels Martin Schmidt

The 2013 season at Zackenberg, proceeded largely as planned. The season started 23 March and ended 30 October. A total of 91 researchers visited the station. The total number of 'bed nights' was 2752 (1877 related to research and monitoring, and 875 to logistics). Of the 2752 'bed nights' related to research and monitoring, 749 'bed nights' were primarily related to in house monitoring, while 1128 was used by external research projects.

The long-awaited bridge over the river Zackenberg was established. The building of the bridge was financially supported by Crown Prince Frederik and Crown Princess Mary's Foundation, A.P. Møller and Chastine Mc-Kinney Møller's Foundation for General Purposes, Aage V. Jensen Charity Foundation, Dr. René Vejlsgaard's Foundation, the Danish Environmental Protection Agency and the Danish Energy Agency.

Data collection for Zackenberg Basic was carried out according to the manuals for the individual sub-programmes.

A new book about Zackenberg Research station was published '*Zackenberg – on the edge of winter*' by Mads C. Forchhammer. The book provides an interesting insight into the lives and fieldwork of the researchers in the high Arctic and a unique portrait of the winter at one of the most isolated research stations in the Arctic.

Zackenberg research Station had a new scientific leader; Niels Martin Schmidt, Senior Researcher at Department of Bioscience, Aarhus University took over as new Scientific Leader 1 January 2013.

Zackenberg Basic was involved in several larger international research projects: Defrost (Nordic Centre of Excellence, led by Torben Røjle Christensen, Lund University), Page 21 (EU project with relevant work packages led by Hanne Christiansen, University Centre in Svalbard (UNIS)) and CENPERM (Centre for Permafrost Dynamics in Greenland led by Bo Elberling, Copenhagen University). Zackenberg Basic is also involved in INTERACT (International Network for Terrestrial Research and Monitoring in the Arctic), in SIOS (Svalbard Integrated Arctic Earth Observing System) and in CBMP (Circumpolar Biodiversity Monitoring Programme). CBMP has strong international linkages to global biodiversity initiatives and is the biodiversity component of the Sustaining Arctic Observing Networks (SAON). Zackenberg Basic featured prominently in the comprehensive circum-arctic Arctic Biodiversity Assessment, which was published by CAFF in 2013.

Researchers from Zackenberg Basic are also involved in/associated with the Arctic Research Centre at Aarhus University and Arctic Science Partnership (Aarhus University, Greenland Institute of Natural Resources and the University of Manitoba (Canada)).

Economy

In 2013, the monitoring programme Zackenberg Basic received almost 8.5 million DKK from the Danish Energy Agency and the Environmental Protection Agency for the five programmes – ClimateBasis, GeoBasis, GlacioBasis, BioBasis and MarineBasis. The funding includes means for long-term monitoring as well as analytical and strategic initiatives. On top of this, the five Zackenberg Basic monitoring programmes co-funded the monitoring with approximately 1.2 million DKK.

Zackenberg Research Station received 3.2 million DKK from the Danish Agency for Science, Technology and Innovation for running and maintaining the station, salaries and logistics support, and the Zackenberg secretariat.

During the period March to October 2013, twenty-eight projects visited the station. Among these were ClimateBasis, GeoBasis, GlacioBasis, BioBasis and MarineBasis programmes, as well as 23 external research projects. The overall economy of the external research projects is not known, and therefore only funding related to travels and accommodations are presented below – not salaries and laboratory analyses.

The five Zackenberg Basic monitoring programmes spent almost 1.74 million DKK on logistics handled by the station (travel, accommodation, cargo and subsistence); while the external funded research projects spent approximately 2.54 million DKK on logistics handled by the station.

Eight externally funded research projects (18 researchers) were supported by the INTERACT Transnational Access with almost 1.2 million DKK (which includes 302 'bed nights').

In 2013, more than 29 peer-reviewed papers were publish by researchers from the Zackenberg Basic programme and from externally funded research projects. Amongst these papers, several papers appeared in top-ranking journals, such as Nature Climate Change.

Executive summary

Jakob Aberman, Magnus Lund, Michele Citterio, Niels Martin Schmidt, Mikael Sejr and Lillian Magelund Jensen

Introduction

The 2013 season was another busy year at Zackenberg Research Station with a field season starting 23 April and ending 30 October. 91 scientists from 28 different projects visited the station, and the total number of bed nights this season was 2752.

ClimateBasis and GeoBasis

The year 2013 was characterized by low amounts of snow during the preceding winter. Maximum snow depth at the climate station did not exceed 0.12 m, which was the lowest snow depth on record. Snow depletion began already in the beginning of May, and the valley was snow free 20 days earlier than in 2009, which, until 2013, was the year with least amounts of snow. By 1 June, all snow had melted at the climate station. In the mid-October 2013, the valley was covered by 0.1-0.2 m of snow.

The annual mean air temperature in 2013 was with –9.0 °C close to average. Winter months were slightly colder than average whereas summer months were warmer. The first occurrence of positive air temperature was 10 January during a wintertime hot spell, while a maximum temperature of 17.6 °C was measured 27 July. Night frost occurred in all summer months, and the first negative mean daily temperature in the autumn was measured 9 September. Annual precipitation was close to average; however, winter months were dry while especially August and September were remarkably wet due to heavy rainstorms.

The river Zackenberg broke up 30 May, and a gradually increasing discharge with a pronounced diurnal cycle was recorded until late June. A major flood occurred 11 July resulting in peak discharge levels (approximately 120 $m^3 s^{-1}$) with subsequent changes in the riverbed. Total runoff for the river Zackenberg during 2013 was estimated to be 147 million m^3 and total suspended sediment transport amounted to 45 350 ton. The ice-dammed lake at A.P. Olsen Land was almost empty in spring 2013. However, it grew during the course of early summer, reached its maximum 9 July and drained between 9 and 11 July.

The active layer depth monitoring in 2013 in the two CALM plots (ZEROCALM-1 and ZEROCALM-2) began early due to early snowmelt. Maximum thaw depths, reached in late August, were slightly less than the maxima measured at these grids in 2012. Average maximum depth of active layer in 2013 was, however, close to average maximum thaw depths from previous years.

Methane (CH_4) fluxes were measured at the fen site from 8 June until 27 October. In general, CH_4 emissions were lower compared with previous years, likely related to dry growing season conditions with low water table levels. The temporal and spatial variation in CH_4 fluxes were studied in detail in relation to a master thesis work by GeoBasis associate Kirstine Skov. The temporal variation was mainly controlled by soil temperature and water level depth, whereas the spatial variation was regulated by soil moisture and vegetation density and composition.

Fluxes of carbon dioxide (CO_2) were monitored both at a heath site and at a fen site. At the heath site, measurements began 1 May and lasted until 26 October. The daily net uptake period began already 14 June, which together with 2005 and 2009 is the earliest onset of net uptake period on record. The accumulated CO_2 uptake during the net uptake period in 2013, –26.8 g C m^{-2}, was close to the mean of all measurement years. During the entire measuring period (178 days), the net CO_2 budget amounted to –0.7 g C m^{-2}. Taking the rest of the year into account when small CO_2 emissions can be expected, the heath likely constituted a net source for atmospheric CO_2.

In autumn 2012, the eddy covariance system in the fen was for the first time allowed to continue to run unattended, powered by solar panels, fuel cells and batteries. Unfortunately, the fuel cells broke down in early winter and therefore there were long periods of gaps during the winter. The net CO_2 uptake period in the fen lasted between 17 June and 9 August. During this period, the fen accumulated –149.0 g C m^{-2}. During the period 1 April–25 October, the CO_2 budget of the fen ecosystem amounted to –76.3 g C m^{-2}.

GlacioBasis

The GlacioBasis monitoring programme at the A.P. Olsen Ice Cap in the river Zackenberg catchment (NE Greenland) started in March 2008, with subsequent field visits taking place every year during springtime. In 2013, the monitoring, processing and data management tasks carried out included:

- Maintenance of three automatic weather stations (AWS), two of which are with satellite telemetry to Denmark
- Measurement and re-drilling of the network of ablation and displacement stakes
- Survey of surface velocity and elevation by dual frequency differential GPS
- Recording and post-processing of dual frequency GPS data, providing high accuracy positions of master and rover GPS receivers. Within a collaboration with Bo Vinther, (Centre for Ice and Climate (CIC), University of Copenhagen) a shallow firn core has been drilled at the summit of A.P. Olsen Ice Cap, next to a GlacioBasis AWS, and will be analysed at CIC
- As part of a wider campaign by Marek Stibal to study the microbiology of glaciated surfaces in Greenland, ice samples for microbiological investigations have been collected at the sites of the lower and intermediate GlacioBasis AWS
- Collaboration with the Zentralanstalt für Meteorologie und Geodynamik (Vienna, Austria) colleagues monitoring the glacier dammed lake
- Initiated the acquisition and archiving in a spatially-enabled database for future processing of a comprehensive set of optical remote sensing datasets in the visible and infrared bands, consisting of the complete Landsat collection to date
- Standardized data validation and archival, including preliminary specification of metadata for the new GEM database
- Contributed to the establishment of the CryoNet *in situ* observation network within the World Meteorological Organization (WMO) Global Cryosphere Watch (GCW), and promoted GEM and PROMICE as initial WMO CryoNet sites in Greenland

Fieldwork and data management in 2013 were completed as planned with the exception of radar snow surveys, which could not be carried out due unfavourable ground conditions. However, snow depths at the ablation stakes have been measured. The snow cover on the glacier and in the glacier terminus foreland was the lowest observed of all previous years, severely restricting mobility on the glacier and between the glacier and Zackenberg Research Station and requiring camping at the terminus.

As part of a wider campaign by Marek Stibal to study the microbiology of glaciated surfaces in Greenland, the GEM 2011-2015 strategy intermediate weather station, located in the upper ablation area, has been equipped with radiometers to measure the surface radiative fluxes.

BioBasis

For BioBasis, the 2013 field season the low snow cover and the resulting early onset of spring marked the pattern of plant flowering phenology and vegetation greening, with earlier than average onset of flowering and lower than average peak NDVI. In addition, the flower production was low in most plots.

As for the plant phenology plots, the arthropod plots were also snow-free early in the season. The number of arthropods caught was very low in 2013, especially for the Chironomids.

During the breeding bird census, the number of territories was generally around the average of previous years for all species. The number of snow bunting territories, however, was higher than in previous years. While the nest initiation of common ringed plover nest initiation was early, the breeding phenology of the remaining wader species was around the average of previous years. The predation pressure was high, and less than 20% of all wader nests were successful. In addition, the skua nested earlier than average. Only relatively few skua nests were found, reflecting the relatively low numbers of lemmings in 2013. None of the lemming winter nests registered showed sign of stoat depredation.

Breeding was observed in three Arctic fox dens, with 12 pups. The number of muskoxen in the valley was above average, and with a rather stable sex and age composition during the season.

Consistent with the low snow cover in the valley, the lakes were also ice-free early. This year the temperature in the lakes were among the highest recorded so far. Most water chemistry measures were within the range of previous seasons, but chlorophyll values were low compared to previous years.

Marine Basis

The 2013 season was the 11th of the marine monitoring programme. It was characterized by an ice free season spanning from 2 July to 15 October resulting in 105 days of open water, which exceeds the average 97 days observed since 2003. The mooring placed in 2012 equipped with two CTDs, the sediment trap was recovered, and all instruments had worked as scheduled during the deployment. Due to technical difficulties the samples from the sediment trap has not been analysed yet but will be available later. Compared to the 2010 and 2011 seasons where the seasonal measurements from CTDs on the mooring have revealed a freshening of the fjord, 2012 was characterized by an increase in salinity at the mooring site. In 2013, a freshening was again observed.

The three-week field campaign in late July-early August revealed the typical hydrographic conditions with a thin freshwater wedge in the top 5-8 m of the inner fjord. The terrestrial melt water with its load of inorganic particles influence light conditions in the fjord and concentrates light absorption in the surface leading to relative high temperatures above 10 °C at the surface. The changes in light conditions along the fjord transect influence the distribution of fluorescence and O_2 concentrations.

The phytoplankton community consisted of the usual species and was dominated by diatoms species of the genus *Chaetoceros*. Species richness and diversity was close to average for the 2003-2012 period. Zooplankton show a higher than usual dominance of the small copepod species Oithona which constituted 68 % of all specimens sampled. Values of $p\mathrm{CO}_2$ in the surface were very high resulting in lowest average $\Delta p\mathrm{CO}_2$ values recorded at the 'Main Station' of just –34 ppm. Oxygen uptake by the sediment and annual growth of the kelp *Saccharina latissima* was close to average values for the programme.

Research projects

22 research projects were carried out at Zackenberg Research Station in 2013. Of these five projects were parts of the Zackenberg monitoring programmes. Nineteen projects used Zackenberg Research Station as a base for their activities, and one project used Daneborg. Two projects used both Zackenberg and Daneborg as a base for their activities.

1 Introduction

Niels Martin Schmidt, Torben Røjle Christensen and Lillian Magelund Jensen

The 2013 season was another busy season at Zackenberg. The field season started 23 April and ended 190 days later on 30 October. Ninety-one scientists from 28 different projects visited the station, resulting in a total number of 2752 bed nights this season.

VIP visits

Two VIP visits were carried through during the 2013 season. The first VIP group visited Zackenberg 24–27 June. The VIP guests included HRH Crown Prince Frederik of Denmark, the Greenlandic Minister of Education, Ecclesiastical Affairs, Culture and Gender Equality, Nick Nielsen and the Danish Minister of Higher Education and Science, Morten Østergaard, and representatives from the two major Danish charity foundations, Aage V. Jensen Charity Foundation and Villum Foundation, the rector for Aarhus University and other representatives from Aarhus University, and the director of the Institute of Natural Resources, Nuuk.

The second VIP group visited Zackenberg 20–21 August, and the VIP guests at this visit included the Greenlandic Minister of Housing, Nature and Environment, Miiti Lynge, and the Danish Minister of Climate, Energy and Building, Martin Lidegaard, as well as representative from the Greenlandic and Danish ministries and Aarhus University. The Danish Broadcasting Corporation also participated in the latter visit, and Zackenberg Research Station featured on multiple news platforms.

VIP visit to Zackenberg 24–27 June 2013. From left to right: the Danish Minister of Higher Education and Science, Morten Østergaard, the Greenlandic Minister of Education, Ecclesiastical Affairs, Culture and Gender Equality, Nick Nielsen, HRH Crown Prince Frederik of Denmark and Scientific Leader of Zackenberg Research Station, Niels Martin Schmidt, Aarhus University. Photo: Morten Rasch.

New bridge across the river Zackenberg

The year 2013 was also the year where the long-awaited bridge over the river Zackenberg was established. The building of the bridge was financially supported by Crown Prince Frederik and Crown Princess Mary's Foundation, A.P. Møller and Chastine McKinney Møller's Foundation for General Purposes, Aage V. Jensen Charity Foundation, Dr. René Vejlsgaard's Foundation, the Danish Environmental Protection Agency and the Danish Energy Agency.

Zackenberg – on the edge of winter

In August 2013, Mads C. Forchhammer's artistic book *Zackenberg – on the edge of winter* about Zackenberg Research Station in North-East Greenland was published. The book provides an interesting insight into the lives and fieldwork of the researchers in the high Arctic and a unique portrait of the winter at one of the most isolated research stations in the Arctic.

International cooperation

In 2013, Zackenberg Basic featured prominently in the comprehensive circum-arctic Arctic Biodiversity Assessment, which was published by CAFF in 2013. The lessons learned over the years at Zackenberg and the experiences of Zackenberg Basic are also central to the development of protocols for the circum-arctic monitoring of biodiversity within the Circumpolar Biodiversity Monitoring Program (CBMP). CBMP is an international network of scientists, government agencies, Indigenous organizations and conservation groups working together to harmonize and integrate efforts to monitor the Arctic's living resources. The CBMP coordinates marine, freshwater, terrestrial and coastal ecosystem monitoring activities and develops best practice protocols for monitoring. CBMP has strong international linkages to global biodiversity initiatives. CBMP is the biodiversity component of the Sustaining Arctic Observing Networks (SAON).

As part of the Greenland Ecosystem Monitoring (GEM), Zackenberg also plays a central role in the EU project 'International Network for Terrestrial Research and Monitoring in the Arctic' (INTERACT), and GEM is co-leading the project and coordinating two work packages within the project. In 2013, the transnational access (TA) component of INTERACT enabled 18 researchers from eight projects to visit Zackenberg free of charge, spending a total of 302 bed nights.

The new bridge across the river Zackenberg September 2013. Construction workers (from left to right): Jørn Ladegaard (Aarhus University), Flemming Nielsen (Bladt Industries), Martin Højholt (Bladt Industries), Konrad Bøknæs (Bladt Industries), Flemming Bach (Bladt Industries), Kenny Madsen (Aarhus University), Søren Overgård (Bladt Industries). Photo: Jørgen Skafte.

New Scientific Leader
Niels Martin Schmidt (nms@bios.au.dk), Senior Researcher at Department of Bioscience, Aarhus University took over as new Scientific Leader of Zackenberg Research Station 1 January 2013.

Outreach
Results from the Zackenberg Basic monitoring programme are continuously published in scientific papers and popular science articles. Furthermore, data from the Zackenberg Basic programme is freely available and was also in 2013 used for reporting purposes in a number of international fora and by a number of externally funded research projects.

In 2013, more than 29 peer-reviewed papers were publish by researchers from the Zackenberg Basic programme and from externally funded research projects. Amongst these papers, several papers appeared in top-ranking journals, such as Nature Climate Change. Additionally, scientists working at Zackenberg presented their work in Danish and international newspapers and radio several times in 2013.

Throughout the field season, visiting scientists are encouraged to post diaries describing the daily life at Zackenberg on the web site (www.zackenberg.dk).

Further information

For further information about Zackenberg Research Station and the work at Zackenberg are collected in previous annual reports available at the Zackenberg web site (www.zackenberg.dk). On the web site, one can also access the ZERO Site Manual, manuals for each of the monitoring sub-programmes, a database and a GIS-database with freely available data from the monitoring programmes, as well as an updated Zackenberg bibliography.

The Zackenberg Research Station address is:

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Zackenberg Research Station.
Photo: Henrik Spanggård Munch.

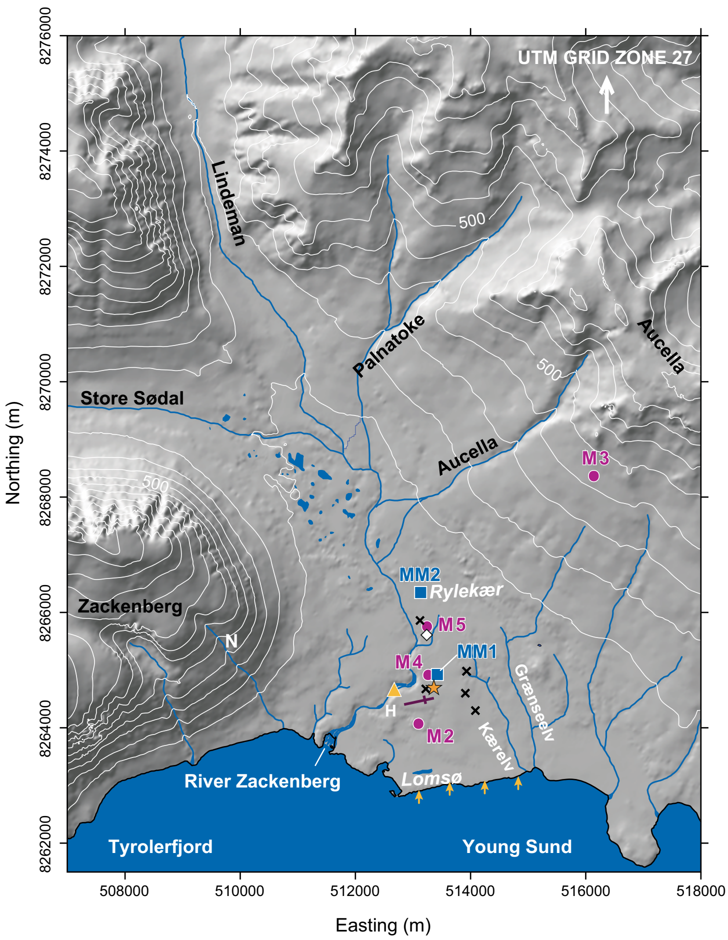
2 Zackenberg Basic

The ClimateBasis and GeoBasis programmes

Maria Rask Mylius, Torben R. Christensen, Per Hangaard, Birger Ulf Hansen, Dorthe Petersen, Mikkel P. Tamstorf, Mikhail Mastepanov, Majbritt Westring Sørensen, Lau Gede Petersen, Laura Helene Rasmussen, Charlotte Sigsgaard, Kirstine Skov, Jakob Abermann and Magnus Lund

GeoBasis and ClimateBasis provide long-term data of climatic, hydrological and physical landscape variables describing the environment at Zackenberg. This includes climatic measurements, seasonal and spatial variations in snow cover and local microclimate in the Zackenberg area, the water balance of river Zackenberg drainage basin, the sediment and solute transport of the river Zackenberg, the carbon dioxide (CO_2) and methane (CH_4) fluxes from a well-drained heath and from a fen area, the seasonal development of the active layer, temperature conditions and soil water chemistry of the active layer, and the dynamics of selected coastal and periglacial landscape elements. For a map of the main study sites, see figure 2.1.

Figure 2.1 GeoBasis and ClimateBasis plots. Asterix = Meteorological station. H = Hydrometric station. Red squares = Eddy towers. Circles = Snow and micrometeorological stations. Triangles = Water sample site. N = Nansen-blokken (photo site). Crosses = Soil water sites. White square = Methane site. Arrows = Coastal cliff recession.



GeoBasis is operated by Department of Bioscience, Aarhus University, in collaboration with Department of Geosciences and Natural Resource Management, University of Copenhagen. In 2013, GeoBasis was funded by Danish Ministry for Climate and Energy as part of the environmental support programme DANCEA – Danish Cooperation for Environment in the Arctic. ClimateBasis is run by Asiaq – Greenland Survey who operates and maintains the meteorological station and the hydrometric station. ClimateBasis is funded by the Government of Greenland.

More details about sampling procedures, instrumentation, locations and installations are given in the GeoBasis Manual and the ClimateBasis Manual. Both can be downloaded from www.zackenberg.dk. Selected validated data from the monitoring programmes are also accessible from this website. For other validated GeoBasis data – please contact Maria Rask Mylius (mrp@ign.ku.dk) or programme manager Magnus Lund (ml@bios.au.dk). For matters concerning the ClimateBasis programme and data please contact Jakob Abermann (jab@asiaq.gl).

2.1 Meteorological data

The climate station at Zackenberg was installed during summer 1995. Technical specifications of the station are described in Meltofte and Thing (1996). Once a year the sensors are calibrated and checked by Asiaq – Greenland Survey.

Data for 2012 and 2013 are shown in figure 2.2 and monthly mean values of climate parameters for 2013 are shown in table 2.1.

Annual values for selected parameters from 1996 to 2013 and mean wind statistics are summarized in tables 2.2 and 2.3, respectively. Temperatures in 2013 were close average with below average winter months temperatures balancing above

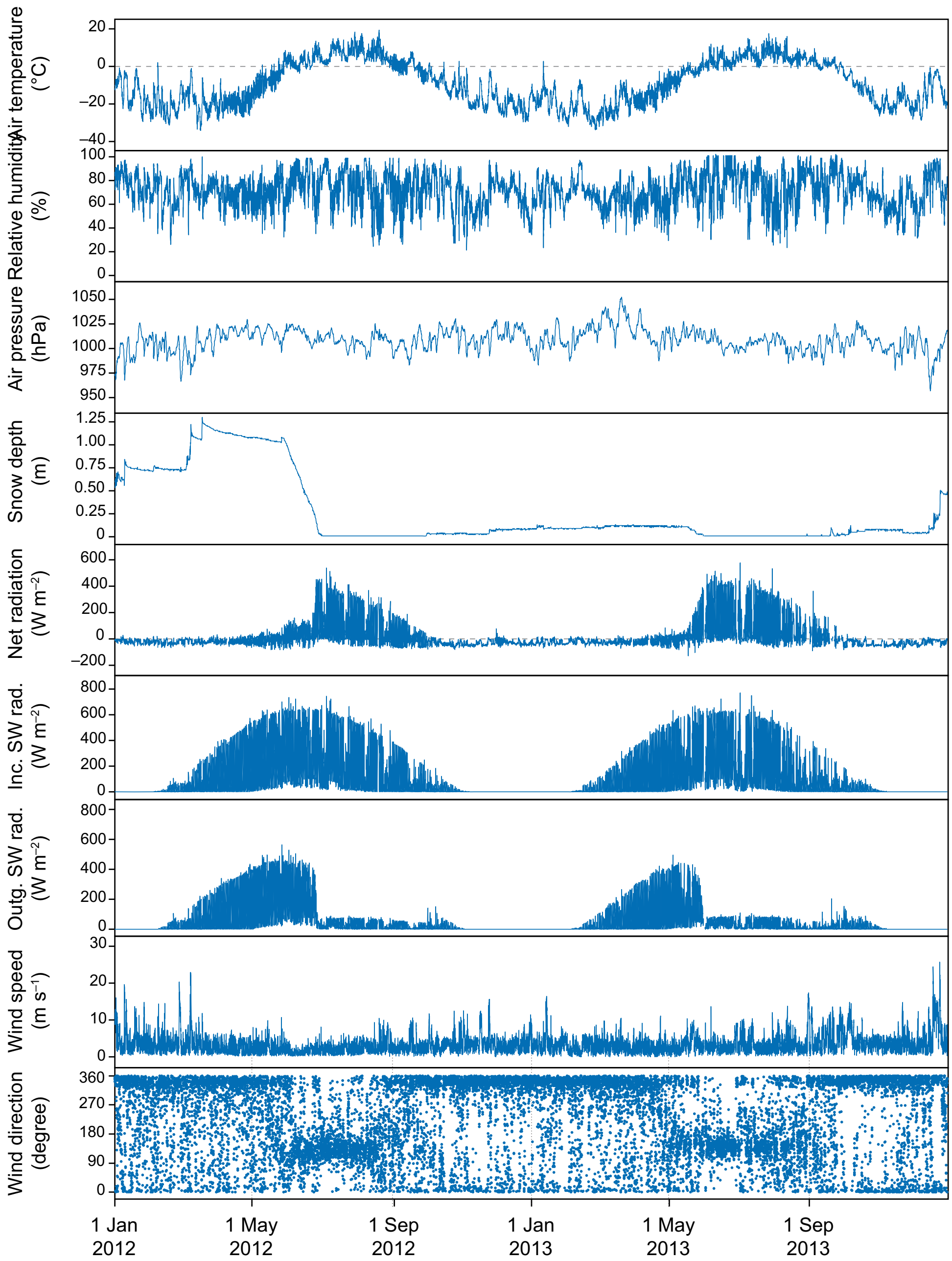


Figure 2.2 Variation of selected climate parameters during 2012 and 2013. Wind speed and direction are measured 7.5 m above terrain; the remaining parameters are measured 2 m above terrain.

Table 2.1 Monthly mean values of climate parameters 2013.

Year	Month	Air temperature (°C)		Rel. humidity (%)	Air press. (hPa)	Net rad. ($W m^{-2}$)	Shortwave rad. ($W m^{-2}$)		Wind velocity ($m s^{-1}$)		Dominant wind dir.
		2.0 m[1)]	7.5 m				In	Out	2.0 m	7.5 m	7.5 m
2013	Jan	−18.8	−17.7	69	1006.7	−25	0	0	2.6	3.6	NNW
2013	Feb	−23.1	−21.9	73	1013.8	−18	6	6	1.9	2.7	NNW
2013	Mar	−20.2	−19.1	64	1029.4	−26	58	51	2.2	3.0	NNW
2013	Apr	−15.4	−14.5	64	1013.7	−20	169	140	1.8	2.4	NNW
2013	May	−3.9	−4.0	75	1014.0	30	243	160	2.5	3.3	SSE
2013	June	3.0	2.5	81	1005.2	176	290	39	2.6	3.0	SE
2013	July	7.2	6.9	72	1005.7	134	232	34	2.7	3.3	SE
2013	Aug	5.4	5.4	73	1001.4	–*	128	20	3.0	3.8	SE
2013	Sept	1.4	1.4	80	1003.6	–**	50	13	3.7	5.0	NNW
2013	Oct	−11.4	−10.7	73	1011.0	−32	14	12	3.5	4.8	NNW
2013	Nov	−19.4	−18.3	60	1001.4	−39	0	0	2.6	3.5	N
2013	Dec	−14.3	−13.7	73	998.6	−22	0	0	4.4	5.7	N

* – only 75% of the data exists
** – only 66 % of the data exists

Table 2.2 Annual mean, maximum and minimum values of climate parameters from 1996 to 2013.

Year	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Annual mean values																		
Air temp. 2 m above terrain (°C)	−9.0	−10.1	−9.7	−9.5	−10.0	−9.7	−8.6	−9.2	−8.5	−7.7	−8.1	−8.7	−8.1	−9.4	−9.7	−8.5	−8.9	−9.0
Air temp. 7.5 m above terrain (°C)	−8.4	−9.3	−9.1	−8.9	−9.4	−9.2	–	−8.7	−7.9	−6.9	−7.6	−8.2	−7.9	−8.6	−8.6	−7.4	−7.9	−8.6
Rel. air hum. 2 m above terrain (%)	67	68	73	70	70	71	72	71	72	71	72	69	72	71	73	74	72	71
Air pressure (hPa)	1009	1007	1010	1006	1008	1009	1009	1008	1007	1008	1007	1006	1008	1010	1012	1005	1009	1009
Incoming short-wave radiation ($W m^{-2}$)	113	104	101	100	107	112	105	104	99	101	107	107	107	104	104	104	108	99
Outgoing short-wave radiation ($W m^{-2}$)	52	56	55	56	52	56	54	49	42	43	54	45	52	38	45	45	57	40
Net radiation ($W m^{-2}$)	16	9	6	4	14	13	–	8	–	–	10	13	8	13	9	13	5	16
Wind velocity 2 m above terrain ($m s^{-1}$)	2.7	3.0	2.6	3.0	2.9	3.0	2.8	2.6	3.0	2.9	2.8	2.6	2.9	2.6	2.4	2.6	2.4*	2.8
Wind velocity 7.5 m above terrain ($m s^{-1}$)	3.1	3.4	3.2	3.7	3.3	3.4	3.3	3.1	3.6	3.5	3.4	3.2	3.5	3.2	3.1	3.5	3.1	3.7
Precipitation (mm w.eq.) total	223	307	255	161	176	236	174	263	253	254	171	178	202	169	–	238	93	229
Annual maximum values																		
Air temp. 2 m above terrain (°C)	16.6	21.3	13.8	15.2	19.1	12.6	14.9	16.7	19.1	21.8	22.9	16.4	18.4	18.1	16.1	19.7	19.4	17.6
Air temp. 7.5 m above terrain (°C)	15.9	21.1	13.6	14.6	18.8	12.4	–	16.7	18.5	21.6	22.1	15.6	18.2	17.7	15.7	19.2	17.8	17.1
Rel. air hum. 2 m above terrain (%)	99	99	99	99	100	100	100	100	100	99	99	99	99	101	102	101	100	102
Air pressure (hPa)	1042	1035	1036	1035	1036	1043	1038	1038	1033	1038	1038	1037	1043	1034	1046	1031	1030	1052
Incoming short-wave radiation ($W m^{-2}$)	857	864	833	889	810	818	920	802	795	778	833	769	747	822	804	791	837	793
Outgoing short-wave radiation ($W m^{-2}$)	683	566	632	603	581	620	741	549	698	629	684	547	563	488	607	578	564	561
Net radiation ($W m^{-2}$)	609	634	556	471	627	602	–	580	–	–	538	469	565	548	539	496	537	575
Wind velocity 2 m above terrain ($m s^{-1}$)	20.2	22.6	25.6	19.3	25.6	20.6	21.6	20.6	22.2	19.9	20.8	27.6	24.5	20.5	17.0	26.6	18.6	21.5
Wind velocity 7.5 m above terrain ($m s^{-1}$)	23.1	26.2	29.5	22.0	23.5	25.0	25.4	23.3	25.6	22.0	22.8	29.6	28.9	24.4	23.2	30.1	23.0	25.7
Annual minimum values																		
Air temp. 2 m above terrain (°C)	−33.7	−36.2	−38.9	−36.3	−36.7	−35.1	−37.7	−34.0	−34.0	−29.4	−38.7	−33.9	−35.3	−33.9	−32.5	−32	−34.7	−33.9
Air temp. 7.5 m above terrain (°C)	−31.9	−34.6	−37.1	−34.4	−34.1	−33.0	–	−32.4	−32.1	−27.9	−37.2	−32.5	−33.9	−33.0	−29.3	−29.2	−31.4	−32.7
Rel. air hum. 2 m above terrain (%)	20	18	31	30	19	22	23	21	17	22	21	18	24	25	22	18	21	23
Air pressure (hPa)	956	953	975	961	969	972	955	967	955	967	968	969	963	967	976	961	967	957
Incoming short-wave radiation ($W m^{-2}$)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Outgoing short-wave radiation ($W m^{-2}$)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Net radiation** ($W m^{-2}$)	−86	−165	−199	−100	−129	−124	–	−98	–	–	−99	−99	−104	−146	−119	−127	−87	−127
Wind velocity 2 m above terrain ($m s^{-1}$)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Wind velocity 7.5 m above terrain ($m s^{-1}$)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

* – only 15 % of data for March exists. **– measured with the NR Lite sensor

Table 2.3 Mean wind statistics based on wind velocity and direction measured at 7.5 m above the surface. Calm is defined as wind speed lower than 0.5 m s-1. Maximum speed is maximum of 10 minute mean values. Mean of maxima is the mean of the yearly maxima. The frequency for each direction is given as percent of the time for which data exist. Missing data amounts to less than 8% of data for the entire year.

	Mean[1)]				2012			2013		
Direction	Frequency	Velocity (m s⁻¹)			Frequency	Velocity (m s⁻¹)		Frequency	Velocity (m s⁻¹)	
	%	mean	mean of max	max	%	mean	max	%	mean	max
N	15.4	4.4	24.5	29.7	11.8	3.8	22.9	17.3	4.9	25.7
NNE	3.6	2.7	18.7	28.9	3.2	2.5	23	3.5	3.2	22.7
NE	2.4	2.4	15.3	23.2	2.5	2.6	12.5	2.2	3.1	17.2
ENE	2.7	2.4	13.1	17.4	2.6	2.0	10.5	2.8	3.5	15.8
E	3.8	2.0	8.5	10.7	3.9	2.1	7.3	2.8	2.1	8.7
ESE	6.6	2.2	8.3	10.3	6.7	2.2	6.3	5.1	2.5	6.3
SE	8.9	2.5	9.3	18.1	8.0	2.4	9.1	8.9	2.9	9.3
SSE	5.8	2.5	9.2	16.2	4.5	2.3	8.7	6.3	2.9	9.1
S	4.1	2.5	7.9	9.9	3.6	2.3	8.3	4.0	2.6	7.2
SSW	2.9	2.2	8.2	13.4	3.0	2.0	7.4	2.9	2.4	6.7
SW	2.6	2.1	7.6	12.2	2.7	2.1	6.1	2.5	2.2	7.1
WSW	3.0	2.3	9.2	15.9	3.2	2.2	6.7	3.1	2.3	7.4
W	2.9	2.4	15.0	23.5	2.8	2.0	8.5	2.4	2.0	7.5
WNW	3.4	2.6	15.7	20.6	3.7	2.5	14.8	3.0	2.2	9.5
NW	6.7	3.5	18.6	25.1	7.6	3.3	20.3	6.1	3.4	15
NNW	22.4	5.0	23.1	30.1	26.9	4.5	22.9	24.3	5.1	24.4
Calm	3.0				3.1			2.3		

[1)] Data from 1997, 1998, 2000, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012 and 2013

average summer months temperatures (figure 2.3). The most unusual weather component of 2013 was the dry winter. With a maximum snow depth value not exceeding 0.12 m it was the thinnest ever recorded. Again, the dry first half of the year was outweighed by a wet August and September, leading to an annual precipitation close to average. The first positive air temperatures in 2013 occurred already 10 January during a lee-wind event, the next time was 13 May. The maximum temperature was 17.6 °C (27 July). During summer, there were seven days, when the mean daily temperature exceeded 10 °C. Monthly mean values of selected climate parameters for June, July and August from 1996 to 2013 are shown in table 2.4. In each summer month of 2013 night frost occurred and the predominant wind direction was from the southeast (SE), which is similar to previous years. Growing degree days (sum of daily mean air temperature above 0 °C) were slightly above average (table 2.5). The first negative mean daily temperature was measured 9 September.

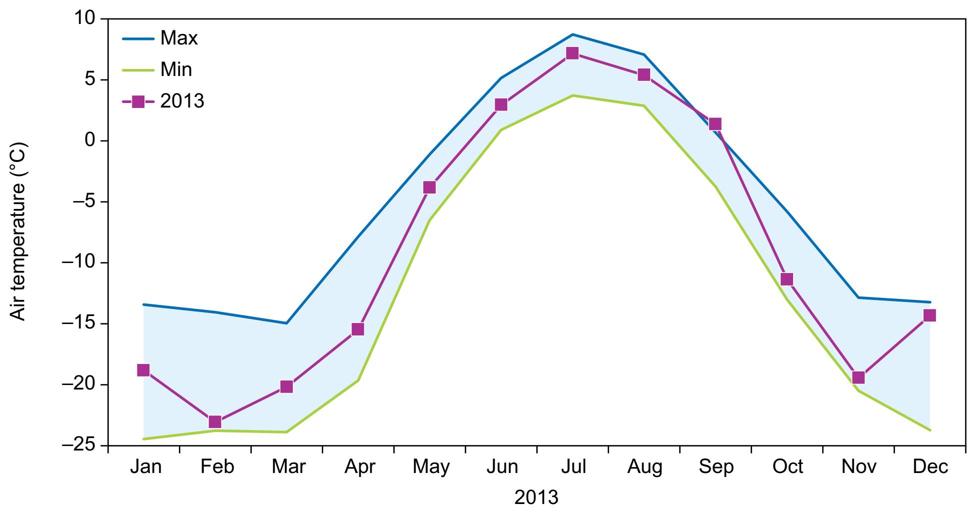


Figure 2.3 Mean monthly air temperatures at Zackenberg as measured at the main climate station during the period 1995-2013.

Table 2.4 Climate parameters for June, July and August, 2003–2013. 1)Wind velocity, max is the maximum of 10 minute mean values. From July 2009 the monthly mean values are calculated based on the 30 minute time series where available.

Year	Month	Shortwave rad. (W m^{-2})		Net rad. (W m^{-2})	PAR (mmol m^{-2} s^{-1})	Air temperature (°C)			Precipitation (mm)	Wind velocity (m s^{-1})		Dominant wind dir.
		mean in	mean out	mean	mean	mean 2 m	min. 2 m	max. 2 m	total	mean 7.5 m	max[1)] 7.5 m	7.5 m
	Jun	294	108	106	612	2.2	–4.8	14.7	7	1.6	5.4	SE
2003	Jul	210	26	96	431	7.7	1.8	16.7	6	2.8	14.2	SE
	Aug	151	20	56	313	6.6	–0.5	15.4	3	2.5	10.1	SE
	Jun	279	73	111	571	2.5	–3.4	19.1	3	2.3	13.6	SE
2004	Jul	225	30	95	464	7.2	–0.7	19.0	10	2.8	10.5	SE
	Aug	150	20	62	302	5.6	–1.4	17.2	4	2.4	12.6	SE
	Jun	261	53	–	519	2.7	–3.5	13.4	6	2.4	11.8	SE
2005	Jul	215	29	–	428	6.9	–0.6	21.8	28	2.9	13.3	SE
	Aug	154	21	51	321	4.6	–2.7	14.0	4	3.2	10.9	SE
	Jun	312	208	54	675	1.0	–4.4	9.5	0	1.7	6.9	SE
2006	Jul	256	28	131	550	6.6	–1.2	22.8	12	2.5	11.3	SE
	Aug	158	21	61	336	5.5	–4.5	16.3	2	2.6	12.0	SE
	Jun	287	86	116	609	3.3	–2.4	15.8	9	2.2	14.8	SE
2007	Jul	251	32	118	531	5.9	–1.8	16.4	8	2.2	6.5	SE
	Aug	149	20	56	320	6.6	–2.6	13.6	6	2.7	12.3	SE
	Jun	284	145	74	612	5.2	–1.5	12.8	3	1.9	11.7	ESE
2008	Jul	260	32	126	551	8.8	0.0	18.4	8	2.8	14.2	SE
	Aug	141	19	51	296	8.0	0.3	17.1	49	3.3	16.9	SE
	Jun	257	32	134	532	1.9	–2.4	9.3	3	2.6	11.0	SE
2009	Jul	233	30	103	487	7.9	0.4	18.1	26	3.3	15.4	SE
	Aug	145	18	48	292	4.4	–1.8	11.6	31	2.8	24.4	SE
	Jun	272	95	98	548	1.9	–8.1	12.8	13	2.0	10.2	SE
2010	Jul	264	40	123	529	5.3	–1.7	15.1	1	2.6	15.7	SE
	Aug	164	27	58	325	5.3	–2.6	16.1	2	2.6	15.0	SE
	Jun	301	84	122	590	2.3	–5.9	13.8	1	2.1	12.3	SE
2011	Jul	255	41	118	503	5.8	–0.8	16.1	6	2.4	15.0	SE
	Aug	149	23	61	–	5.6	–2.4	19.7	33	2.7	12.6	SE
	Jun	295	182	60	–	3.1	–3.7	13.5	2	1.6	9.9	SE
2012	Jul	239	31	117	–	7.4	0.5	18.3	4	2.3	6.6	SE
	Aug	154	24	56	–	7.1	–2.1	19.4	7	2.9	11.8	SE
	Jun	290	39	176	614	3.0	–2.8	12.6	2	3.0	17.2	SE
2013	Jul	231	34	134	496	7.2	–0.8	17.6	7	3.3	12.2	SE
	Aug	127	20	–	276	5.4	–1.3	16.1	76	3.8	17.8	SE

Table 2.5 Positive degree-days calculated on a monthly basis as the sum of daily mean air temperature above 0 °C. Calculations are based on air temperatures from the meteorological station.

Degree days	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Jan										1.5		3.6						
Feby																		
Mar																		
Apr								0.2	1.1		2.9							
May	1.1	1.3	0.1	3.6	0.5	0.5	18.2	3.3	4.1	5.4	3.1		10.0	12.3	0.4	0.6	12.7	3.4
Jun	63.7	74.6	32.5	52.9	71.8	68.2	81.8	74.2	73.9	84.6	37.2	99.7	155.0	64.6	73.3	78.1	95.9	87.5
Jul	181.0	115.4	147.4	192.7	164.4	152.0	175.6	237.2	222.2	214.7	205.3	182.2	270.8	265.6	165.6	180.1	229.4	222.1
Aug	140.5	154.2	143.6	89.2	127.3	181.2	152.5	203.2	169.4	141.5	171.5	204.5	213.7	141.3	164.3	172.5	219.4	167.4
Sep	15.3	4.5	11.3	19.7	5.7	31.1	41.2	42.5	41.4	17.7	15.7	10.1	63.1	8.9	29.6	18.7	32.7	48.7
Oct		1.5				0.3	1.8										0.0	
Nov																		
Dec																		
Sum	401.7	351.5	334.8	358.0	369.7	433.2	471.1	560.6	514.8	466.4	435.7	500.1	712.6	492.7	433.2	450.1	590.0	529.1

2.2 Climate gradients, snow, ice and permafrost

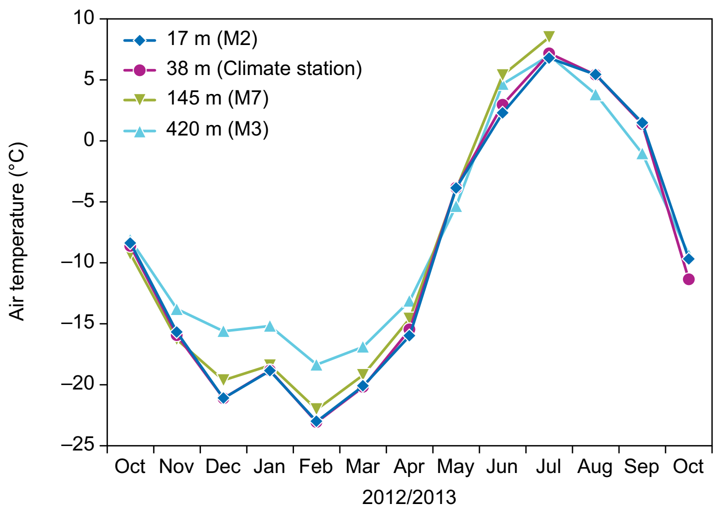
In order to increase the spatial resolution of meteorological data and to describe the gradients (both altitudinal and coast/inland), several smaller automatic weather stations have been installed in the area. In 2003, the station M2 was installed in the valley and the station M3 installed half-way up on Aucellabjerg (Rasch and Caning 2004). M7 was installed in 2008 in the area just west of Store Sø in Store Sødal (Jensen and Rasch 2009). Three automatic weather stations were installed on A.P. Olsen Glacier and data from these are reported in the GlacioBasis chapter.

Monthly mean temperatures from the four weather stations are shown in figure 2.4. The three lower altitude stations (M2, climate station and M7) experienced lower temperatures than M3. Especially during the winter months the valley stations had much lower temperatures than the station at higher elevation. This is mainly due to the effect of cold air sinking down during calm weather and creating frequent inversions. There are few gaps with missing air temperature data. At M2 data is missing from 27 April to 30 April and from 28 October, when data was downloaded for the last time in 2013. The climate station is missing 10 hours data in May and 12 hours data in June. M3 is missing 26 hours of data from 17 August to 18 August, and data is missing from 22 October when data was downloaded for the last time.

Winter hot spells (where the temperature suddenly rises above the freezing point) were only registered at the weather stations on the heath. On 10 January 22:00 the temperature at the Climate station was registered to be 2.7 °C. At M2, 10 January 21.30 the temperature was registered to be 1.2 °C. At M3 and M7 the temperature increased at the same time, but not above the freezing point.

In August 2013 a new weather station, called M8, was established on the mountain Zackenberg. Data will be downloaded from this station in the beginning of the 2014 season. Furthermore, a wireless connection will be installed during summer 2014 to ease data access to the mast.

Figure 2.4 Mean monthly temperatures October 2012 to October 2013 from automatic weather station M2 (17 m a.s.l.), M3 (420 m a.s.l.), the Climate station on the heath (38 m a.s.l.) and M7 (145 m a.s.l.).



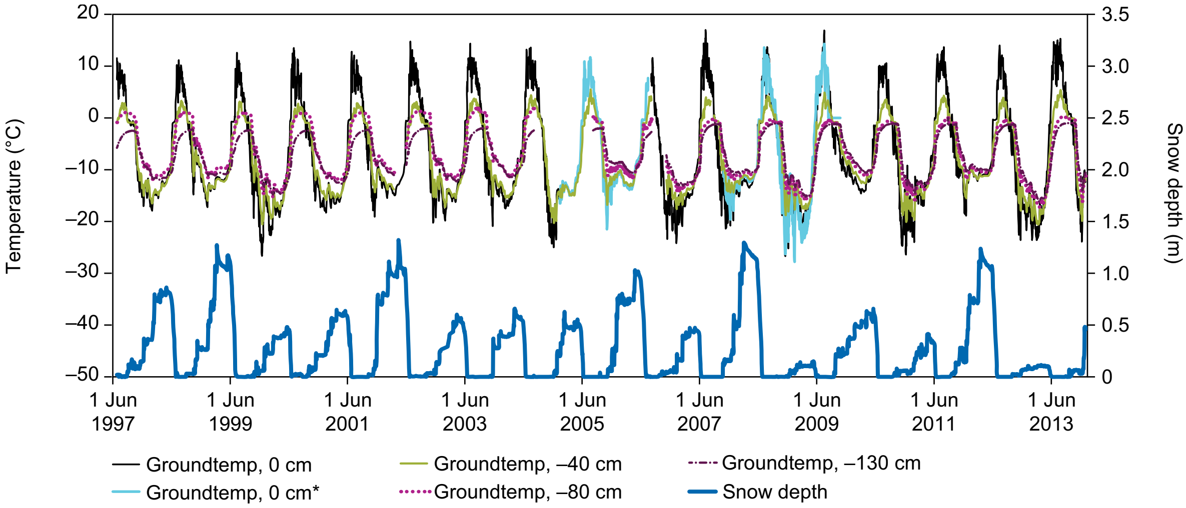


*Figure 2.5 Daily mean soil temperatures and snow depth from the meteorological station. In August 2006 soil temperature sensors were replaced. *Data from sensor at the snow depth station.*

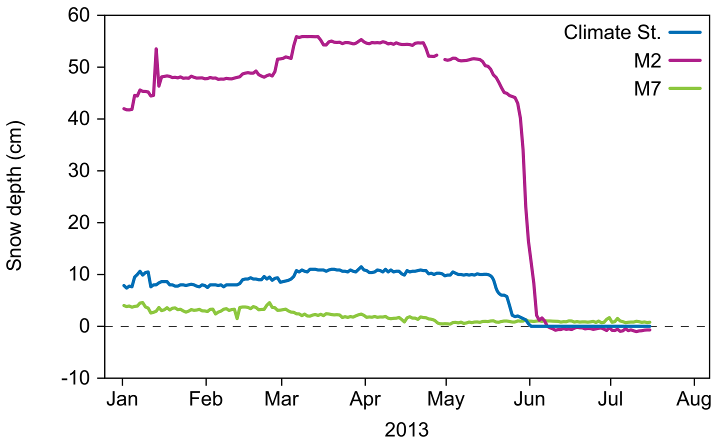


Figure 2.6 Snow depths at the automatic weather stations, M2 (17 m a.s.l.), M7 (145 m a.s.l.) and the Climate station (38 m a.s.l.).

Snow depth

The amount of snow measured at the climate station indicated that the winter 2012/2013 was the most snow-poor year on record. The snow depth was above 0.1 m several times during winter, but there was no continuous snow cover above 0.1 m during winter 2012/2013. On 5 March 2013 the snow started to build up and exceeded 0.1 m only with a few centimetres (table 2.6). The maximum snow depth measured at the climate station was 11.5 cm, which was reached 30 March (figure 2.2 and figure 2.5). Snowmelt started around 16 May and by 1 June the ground was free of snow below the sensor at the meteorological station (table 2.6). Snow depth is also being measured at the automatic weather stations M2, M3 and M7 (figure 2.6). However, the snow depth sensor at M3 had blown off the mast during winter and therefore these data cannot be shown for the winter 2012/13. The peak in snow depth at M2 in January is caused by strong winds and a snowfall in the days before.

In order to achieve a better spatial resolution of snow depths for the modelling, snow depths are also being measured along two main transects; one transect (called SNM) running from Lomsø into the valley and another (called SNZ) running along the ZERO-line from the old delta up to 420 m a.s.l. These snow depths are used as input for the SnowModel covering the central valley.

Table 2.6 Key figures describing the amount of snow at the meteorological station during the last 16 winters.

Winter	1997/1998	1998/1999	1999/2000	2000/2001	2001/2002	2002/2003	2003/2004	2004/2005	2005/2006	2006/2007	2007/2008	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013
Max. snow depth (m)	0.9	1.3	0.5	0.7	1.3	0.6	0.7	0.7	1.1	0.6	1.3	0.2	0.7	0.4	1.3	0.1
Max. snow depth reached	29 Apr	11 Mar	19 May	25 Mar	15 Apr	13 Apr	13 Apr	12 Feb	26 Apr	4 May	6 Mar	17 Feb	19 May	25 Apr	17 Mar	30 Mar
Snow depth exceeds 0.1 m from	19 Nov	27 Oct	1 Jan	16 Nov	19 Nov	06 Dec	24 Nov	27 Dec	19 Dec	12 Jan	26 Oct	29 Jan	25 Sep	26 Jan	14 Oct	5 Mar
Snow depth is below 0.1 m from	25 Jun	3 Jul	14 Jun	24 Jun	20 Jun	14 Jun	13 Jun	7 Jun	1 Jul	8 Jun	24 Jun	16 May	16 Jun	10 Jun	26 Jun	–*

*The winter 2012/2013 had exceptionally low snow height; 0.1 m was reached various times during the winter

By mid-October 2013, the valley was more or less covered by 10 to 15 cm of new snow with a bulk density of 310 kg m^{-3}. As for most occasions with snowfall in the valley, it occurred during periods characterized by high wind speeds packing the snow.

Snow cover

The snow cover in the end of the winter 2012/2013 was very thin and discontinuous, to a degree that has been unprecedented in the Zackenberg valley. Snow depletion started already in the beginning of May. The date of 50 % snow cover was 29 May only five days prior to the date of 50 % snow cover in 2009 (which until 2013 was the year with the earliest onset of snow depletion). However, due to the thin snow cover, the day of complete snow depletion was 20 days earlier than in 2009 (figure 2.7).

The snow cover 10 June is used to compare early season conditions in different sub-sections of the Zackenberg area. In 2013 there were no cloud free camera images from this date; therefore images from 7 June have been used to compute the snow cover values reported in table 2.7. Nonetheless, the snow cover in 2013 in the entire valley was significantly lower than the average and lower than it has ever been in all regions.

*Table 2.7 Area size and snow cover 10 June in 13 bird and mammal study sections in the Zackenberg valley and on the slopes of Aucellabjerg 1995-2013 and mean for the period 1995-2012 (see figure 4.1 in Caning and Rasch 2003 for map of sections). Photos were taken from a fixed point 480 m a.s.l. on the east facing slope of the mountain Zackenberg within +/- three days of 10 June and extrapolated according to the methods described by Pedersen and Hinkler 2000. Furthermore, the proportions of the areas not visible from the photo point are given. *Based on satellite photos (9 June 1995 and 11 June 1996). Blue values are only based on part of the given section due to missing photo coverage. The snow depletion curve for 2013 is computed for 7 June.*

Section	Area (km^2)	Area hidden (%)	1995*	1996*	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Mean (1995-2012)
1 (0-50 m)	3.52	3.5	78	74	65	77	91	60	73	77	68	48	31	74	38	62	13	53	53	77	2	62
2 (0-50 m)	7.97	1.2	89	88	90	85	91	57	87	87	92	49	25	81	43	77	5	61	50	81	2	69
3 (50-150 m)	3.52	0	88	81	83	83	94	51	89	82	83	51	35	77	40	74	11	48	32	86	1	66
4 (150-300 m)	2.62	0	73	74	68	66	86	33	79	56	73	39	28	65	36	54	19	32	23	85	0	55
5 (300-600 m)	2.17	0	16	54	73	43	85	31	56	36	49	16	25	62	25	46	17	12	15	80	0	41
6 (50-150 m)	2.15	75.3	86	86	84	87	98	55	84	78	74	56	50	80	50	59	18	49	29	65	0	66
7 (150-300 m)	3.36	69.3	90	81	76	90	97	54	84	74	90	56	46	82	58	69	34	44	27	57	1	67
8 (300-600 m)	4.56	27.5	49	55	66	64	84	37	45	52	66	30	29	67	26	45	16	25	11	71	1	47
9 (0-50 m)	5.01	6.2	92	87	96	91	97	54	96	96	100	58	23	73	49	80	18	56	72	77	3	73
10 (50-150 m)	3.84	2.9	94	85	95	97	98	60	97	93	100	56	47	92	57	85	43	55	80	92	4	79
11 (150-300 m)	3.18	0.2	91	72	86	92	96	69	97	88	100	66	61	88	54	73	77	51	79	90	9	79
12 (300-600 m)	3.82	0	40	66	89	68	89	65	73	65	98	53	70	85	38	53	64	43	50	71	11	65
13 (Lemmings)	2.05	1	89	80	76	80	87	58	83	83	89	46	25	79	41	73	4	64	54	72	0	66
Total area	45.7	12.9	76	77	81	80	92	54	82	77	83	49	37	77	43	65	28	44	46	78	3	65

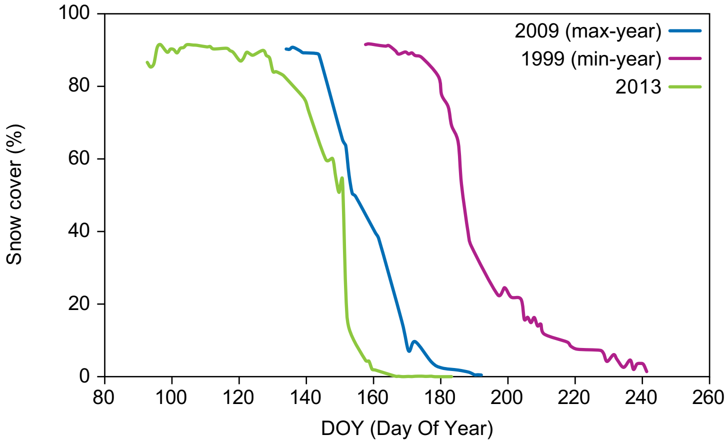


Figure 2.7 Snow depletion curves for the central part of the Zackenberg valley. The curves are shown for 1999 with late snowmelt, 2009 that in the period 1998 – 2012 was the year with the earliest snow depletion and 2013, which has set a new record in early melt off.

Active layer depth

Development of the active layer (the layer above the permafrost that thaws during the summer) starts when the air temperature becomes positive and snow has disappeared from the ground. The depth of soil thaw was measured throughout the field season at two grid-plots; ZEROCALM-1 (ZC-1) covering a 100x100 meter area with 121 grid nodes and ZEROCALM-2 (ZC-2) covering a 120×150 meter area with 208 grid nodes.

In ZC-1, the first grid node was free of snow 18 May and 1 June the first active layers measurements were made when only a few spots of snow were left in this relatively homogenous grid site. The maximum thaw depth was reached by the end of August and was approximately 8 cm less than previous maximum thaw depths measured at these grids last year (figure 2.8 and table 2.8).

In ZC-2, one grid node was free of snow 11 May and the first 33 grid nodes were measured 15 May. The snow patch in ZC-2 was melted away already 16 June and all grid nodes were by then free of snow. The maximum thaw depth was reached at the end of August/early September and the depth was lower than last year's maximum. The average depth of the active layer was lower than previous years, but overall close to the average maximum thaw depth for the site.

Data from the two ZEROCALM-sites are reported to the circumpolar monitoring programme CALM III (Circumpolar Active Layer Monitoring-Network (2009-2014) maintained by the University of Delaware, Centre for International Studies (http://www.gwu.edu/~calm).

Temperature in different settings and altitudes

GeoBasis operates several mini data loggers for year-round temperature monitoring in different altitudes and different geomorphologic settings in the landscape. Positions and a short description of the sites are given in the GeoBasis manual.

Year-round soil temperatures in the active layer are being logged at the meteorological station, at the automatic weather stations M2, M3, M4 and M5 and at the automatic chamber site in the fen (figure 2.1). M4, a 325 cm deep borehole, monitors temperatures from the upper part of the permafrost (Jensen and Rasch 2009). Unfortunately, the battery at M4 had a breakdown during the winter and data from this borehole could not be used. In September 2012, two new and deeper boreholes were established by the Page21 project and by Centre for Permafrost (CENPERM). One borehole is situated nearby M4 (21 metres deep) and the other is south of the runway underneath a snow patch (18 metres deep). These two new boreholes will give a better insight in the temperatures of the deep permafrost.

Figure 2.8 Thaw depth progression in ZEROCALM-1 and ZEROCALM-2 during summer 2013 (green line). Minimum and maximum thaw years (1999 and 2009, respectively) are shown in blue and red, respectively.

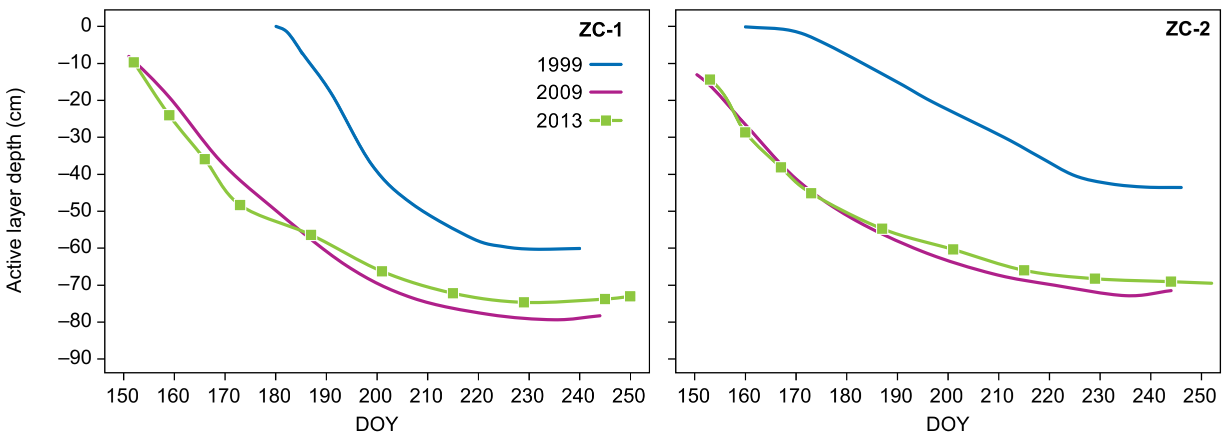


Table 2.8 Average maximum thaw depth (in cm) for grid points in ZEROCALM-1 and ZEROCALM-2 measured late August, 1997-2013.

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
ZEROCALM-1	61.7	65.6	60.3	63.4	63.3	70.5	72.5	76.3	79.4	76.0	74.8	79.4	79.4	78.2	82.0	82.4	74.7
ZEROCALM-2	57.4	59.5	43.6	59.8	59.7	59.6	63.4	65.0	68.6	67.6	67.1	67.5	72.9	69.5	75.3	72.1	69.6

Eight other and shallower boreholes were also established in September 2012 on different vegetation types.

Lake drainage

Photos from the digital camera at the A.P. Olsen Land's glacier dammed lake was retrieved 2 May 2013. The camera was installed in April 2008 to cover fluctuations of the glacier dammed lake (figure 2.9). Daily photos had been obtained since 10 May 2008 except from a gap between October 2009 and May 2010 because of a full memory card. Since there had been so little snow during the winter 2012/2013, the camera had been able to take pictures all winter and was free of snow when personnel visited. The lake had not built up since the huge drainage 6 august 2012 and new ice covered the lake from 8 September 2012. In the beginning of May 2013 when personnel visited there had been no changes in lake size. The lake reached its maximum 9 July and drained between 9 and 11 July.

2.3 River water discharge and sediment transport

The river Zackenberg

The drainage basin of the river Zackenberg includes the Zackenberg valley, Store Sødal, Lindemansdalen and Slettedalen. The basin covers an area of 514 km^2, of which 106 km^2 are covered by glaciers. The first hydrometric station was established in 1995 on the western river bank near the river mouth (Meltofte and Thing 1996). In 1998, the hydrometric station was moved to the eastern bank of the river, due to problems with the station being buried beneath a thick snowdrift

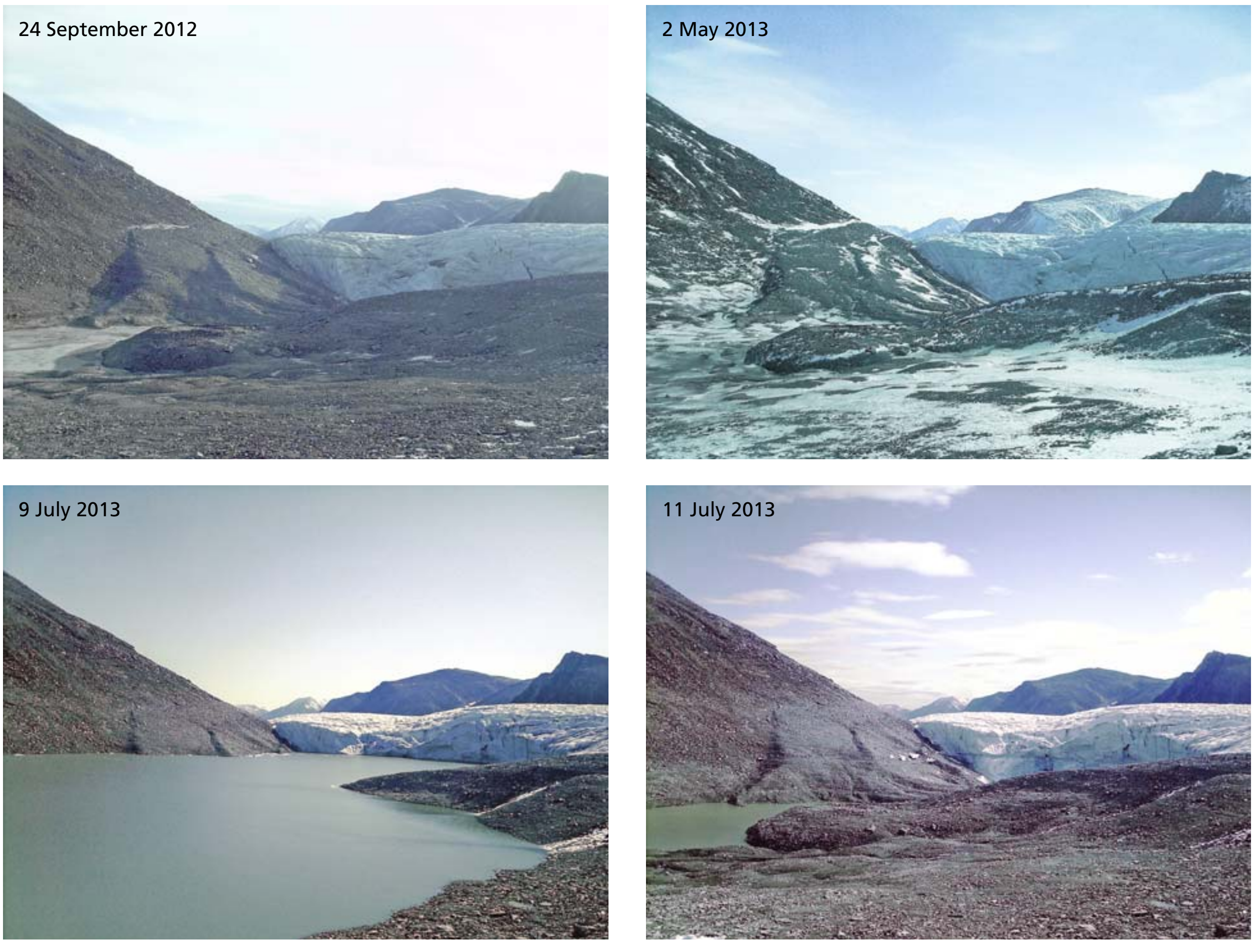


Figure 2.9 Glacier dammed lake at A.P. Olsen Land. The lake was empty in the autumn 2012 and there was no build up during winter 2012/13. The lake drained between 9 July and 11 July 2013.

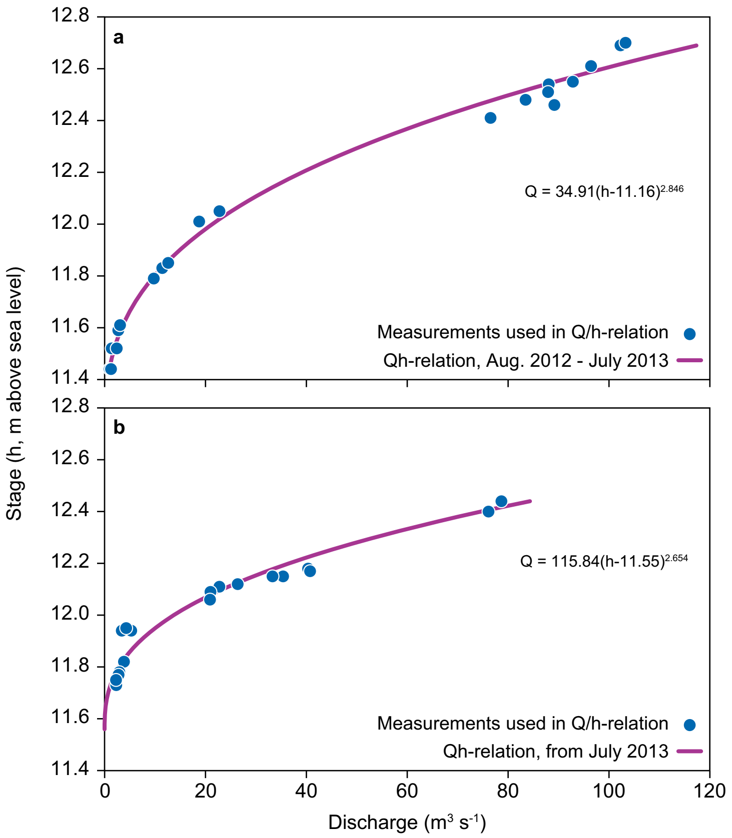


Figure 2.10 Stage-discharge relation (Q/h-relation) for the river Zackenberg at the hydrometric station. a) is valid from 9 August 2012 to 10 July 2013 and has a coefficient of correlation (R^2) of 0.996, while b) is valid after 11 July 2013 with an R^2 of 0.971.

each winter. In the course of the years, the station has been destroyed several times by major floods from the glacier dammed lake at the A.P. Olsen Land.

In 2013, the station was affected by a major flood (11 July). During the flood several discharge measurements were carried out. The flood changed the riverbed but not as significantly as the flood in 2012.

Water level, water temperature, air temperature, conductivity and turbidity are logged automatically every 15 minutes. The water level is measured with a sonic range sensor and various pressure transducers.

Q/h-relation

After a major flood in 2005, the river's cross profile changed and new Q/h-relations have been established almost every year since then. Before 2009 the discharge measurements were carried out either by wading or from boat, which especially at high water levels was difficult to carry out in a safe manner. In 2009, the Danish Environmental Protection Agency donated an Acoustic Doppler Current Profiler (ADCP) of the type Q-liner, which can be operated from land. The discharge measurements have since then been carried out either by wading or with the Q-liner operated from land, depending on the discharge.

In the previous report, the discharge from 2012 was only presented until the flood (6 August 2012). After the flood in 2012 and until the flood in 2013 19 discharge-measurements were carried out which fed into one valid Q/h-relation. After the flood in 2013, 18 additional discharge measurements were carried out. The established Q/h-relations are shown in figure 2.10a and b.

River water discharge

After the flood in 2012, water was running strongly until around 20 August, after which the discharge gradually declined until 17 October when the station was taken down for the winter. In 2013, water started to flow 30 May and a gradual increase of discharge with a pronounced diurnal cycle was recorded until late June (figure 2.11). Discharge decreased and remained comparably low until the flood event 11 July. Several manual discharge measurements were carried out during the flood, which allows an estimate of the maximum discharge of around 120 $m^3\ s^{-1}$. After the flood in 2013, several secondary maxima occurred (late July, early September and late September). While the

Figure 2.11 Water discharge in the river Zackenberg for 2013.

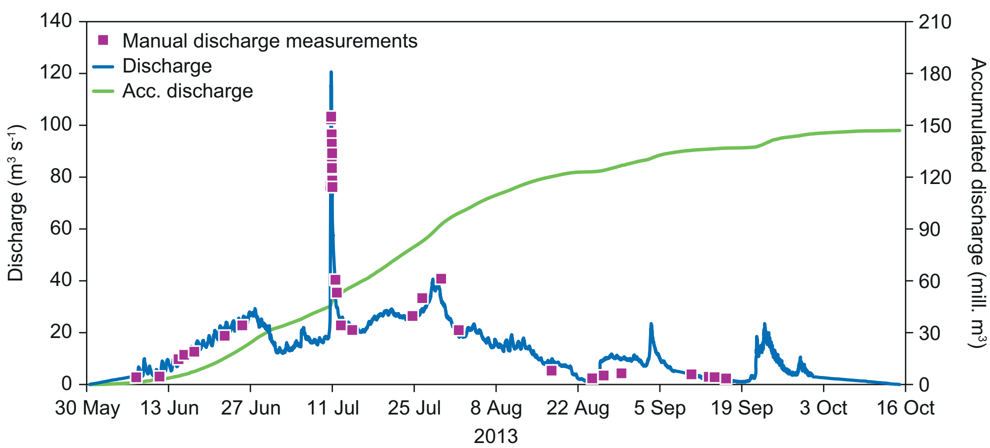


*Table 2.9 Total discharge in the river Zackenberg in the years 1996-2013, corresponding water loss for the drainage area (514 km²) and precipitation measured at the meteorological station. [1]The hydrological year is set to 1 October previous year to 30 September present year. *) For 2005 no data is available during the flood from 25 July 05:00 until 28 July 00:00. After this date and until the new hydrometric station was set up on 5 August the discharge are estimated from manual readings of the water level from the gauge. Total sediment transport during the hydrological year. **) No precipitation data is available from 22 January to 7 April. Therefore no total precipitation as there are too many missing values.*

Hydrological year[1]	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Total discharge (mill. m³)	132	188	232	181	150	137	338	189	212
Water loss (mm)	257	366	451	352	292	267	658	368	412
Precipitation (mm)	239	263	255	227	171	240	156	184	279
Total annual transport									
Suspended sediment (tonnes)		29444	130133	18716	16129	16883	60079	18229	21860
River break-up	late May	4 Jun	10 Jun	9 Jun	8 Jun	8 Jun	4 Jun	30 May	1 Jun
Hydrological year[1]	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Total discharge (mill. m³)	>185*	172	183	201	146	173	197	231	147
Water loss (mm)	>360	335	356	391	284	337	383	449	286
Precipitation (mm)	266	206	133	219	157	>125**	189	166	249
Total annual transport									
Suspended sediment (tonnes)	71319	27214	51118	39039	44716	23538	38337	31066	35344
River break-up	3 Jun	12 Jun	2 Jun	7 Jun	22 May	30 May	23 May	6 Jun	15 May

maximum in July was triggered by temperature and subsequent snow/ice-melt, the high discharge rates in September were connected with strong precipitation events.

After the flood in 2012, approximately 50 million m³ drained from the catchment. In the entire season of 2013 it was 147 million m³ (table 2.9).

Suspended sediment and river water chemistry

Three times a week water samples were collected in the morning (8:00) and in the evening (20:00) in order to determine suspended sediment concentrations (SSC). As shown in figure 2.12b, SSC shows highest concentrations in the early season. At the same discharge rates concentrations of suspended sediment starts to descend in late July and August compared to the first part of the season. A distinct diurnal variation is measured in the early season, which correlates with diurnal discharge variations being more distinct in the early season (figure 2.12a). River discharge was measured until the river began to freeze in again. Usually, the SSC are highest and show larger fluctuations in the afternoon and evening than in the morning.

The highest concentration of SSC during 2013 was 5036 mg l^{-1}, which was measured in the afternoon 10 July when the river burst began. The river burst ended during the night and in the morning (11 July) the sediment concentration in the river water was back to normal for that period.

During the runoff period until 16 October, the suspended sediment transport amounted to 35344 tonnes (table 2.9). In order to compare values between years, the total amount of sediment given is based solely on the SSC measured in the morning, but includes any measurements carried out during flood events. If evening values were included the total transport in 2013 would amount to 45350 tonnes. This indicates that all the calculated sediment yields given in the table are underestimated.

Water samples for dissolved organic content were collected once a week during the season. As shown in figure 2.12c the content is very stable and the two major peaks in September are due to two big rain events.

Daily variations of conductivity and water temperature are shown in figures 2.12d and 2.12e. The very first melt water shows high conductivity; a well-known phenomenon ascribed to solutes being washed out of the snow (Rasch et al. 2000). During the dry summer the conductivity was very stable. The conductivity increases during the river burst and again after a big rain event in the beginning of September. The conductivity in the river peaks during rainy periods due to increased surface and subsurface drainage from land and soil water that has higher conductivity than melt water from the glacier.

Throughout the entire season samples from the river were collected for mercury analysis – water samples and DGT filters. Preliminary results show the same level of mercury content as the previous three years.

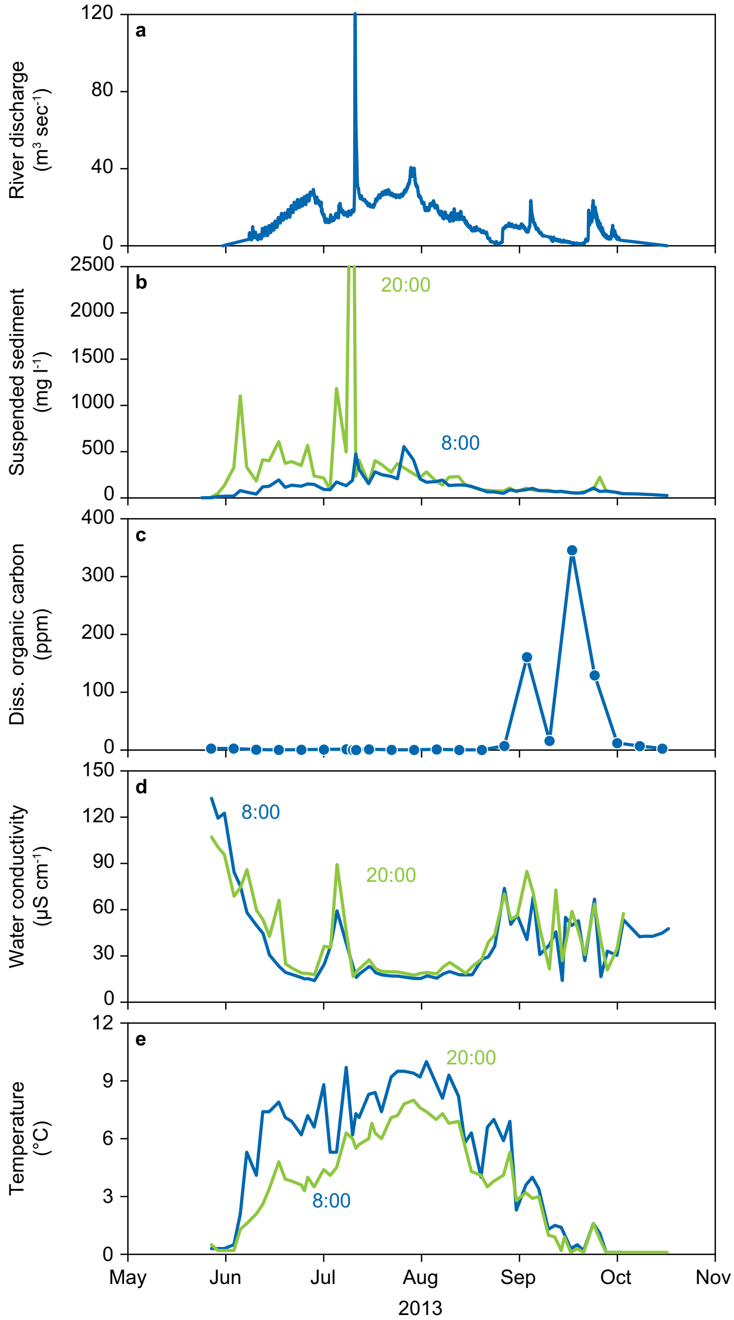


Figure 2.12 Seasonal variations of selected parameters in the river Zackenberg: Discharge (a), suspended sediment concentrations at 08:00 (blue line) and 20:00 (green line) (b), Dissolved organic content (c), Conductivity at 08:00 (blue line) and 20:00 (green line) (d), Water temperature at 08:00 (blue line) and 20:00 (green line) (e).

2.4 Soil water

Soil moisture and soil water

Variation in soil moisture content is measured at several sites. During the field season soil moisture was measured once a week at all the soil water sites and in two transects in ZC-2 (the active layer grid site). Besides the manual measurements, soil moisture is monitored continuously at three automatic stations; M2, M3 and M4 (figure 2.13). M2 is located on a slope and affected by large snow accumulation but dries out quickly due to the primarily sandy material. M3 is located on a gentle slope at 420 m a.s.l. and in early summer this site is affected by flow of melt water from snow patches further up the mountain. Finally, M4 is located in the *Cassiope* heath just north of the meteorological station.

There is almost no temporal offset in the peaks from the three different stations. The thickness of the snowpack was almost the same at all three. At M2 and M4 where the snowpack was thinnest the peak began 30 May (M2) and 29 May (M4), respectively. At M3 the peak was a bit delayed and started 3 June. M3 had a few peaks during July, which was caused by runoff from higher grounds. At M4 a steady drying of the soil was observed until 19 August when the data logger broke down. The logger at M4 will be replaced in the spring of 2014. A steady drying of the soil was observed at M2 and M3 until a big rain event 26 August. Another big rain event was observed in mid-September. In the end of September the soil started to freeze and the soil moisture decreased rapidly at M2 and M3. By mid-October most of the active layer was frozen at these sites.

Three to four times during the season, soil water was collected from various depths in the active layer at four different sites; *Cassiope* heath, *Salix arctica* heath, mixed heath vegetation and a fen site. Water collected from these sites has been analysed for chemical composition.

2.5 Carbon gas fluxes

Carbon gas fluxes are monitored on plot and landscape level in the Zackenberg valley using two measurement techniques:

- Automatic chamber measurements of CH_4 and CO_2 exchange on plot scale in a fen site
- Eddy covariance measurements of CO_2 and H_2O exchange on landscape scale in heath and fen sites

Automatic chamber measurements

The CH_4 exchange has been monitored in six automatic chambers in a wet fen area since 2006 (Klitgaard et al. 2007). During 2011-2012, the automatic chamber system has been expanded to include four new chambers, giving a total of ten chambers.

The temporal variation in CH_4 production is mainly associated with temperature,

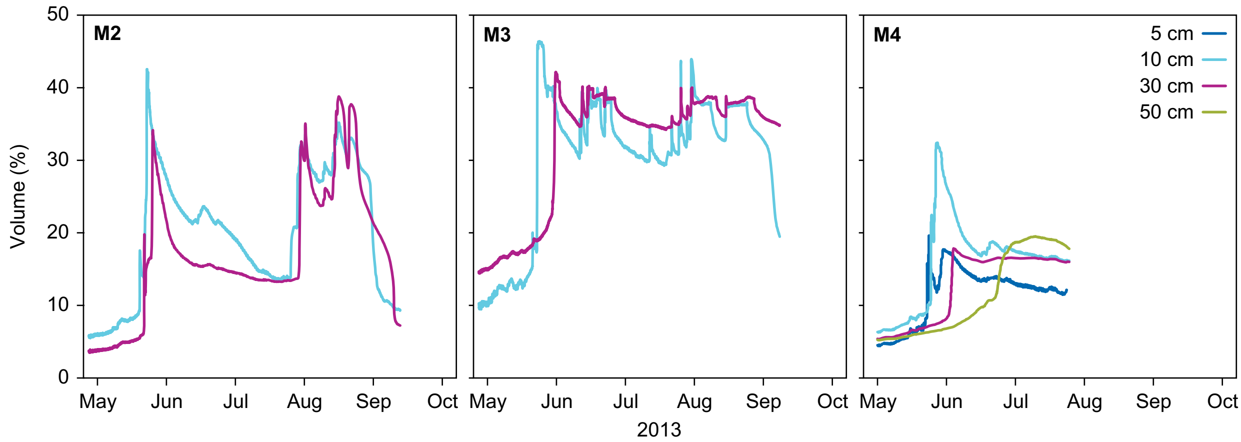


Figure 2.13 Soil moisture content throughout the field season 2013 at the three automatic weather stations M2, M3 and M4.

water table depth and substrate quality and availability. It has also been found from this site that autumn frost action resulting in accumulated CH_4 gas being squeezed out from the soil matrix can be of high importance for the annual CH_4 exchange (Mastepanov et al. 2008).

In 2013, CH_4 flux measurements began 8 June and lasted until 27 October. In general, the measurement system performed well throughout the period with only minor gaps in data due to maintenance and precautionary interruptions during periods with anticipated high wind speeds. During autumn 2013, the GeoBasis associate Kirstine Skov wrote her master thesis on "Spatiotemporal variability in methane emission from an Arctic fen over a growing season – dynamics and driving factors" (Skov 2014), and the following section summarizes her findings.

During the mean growing season 2013 CH_4 emission was low compared with previous years, due to low amount of snowfall, early timing of snowmelt and dry growing season conditions. Temporal variation in CH_4 fluxes (figure 2.14) was largely controlled by environmental factors, most importantly soil temperature but also water level and active layer depth. In terms of spatial variability, three distinct chamber subgroups were identified (figure 2.14), separated by their magnitude of fluxes and location along

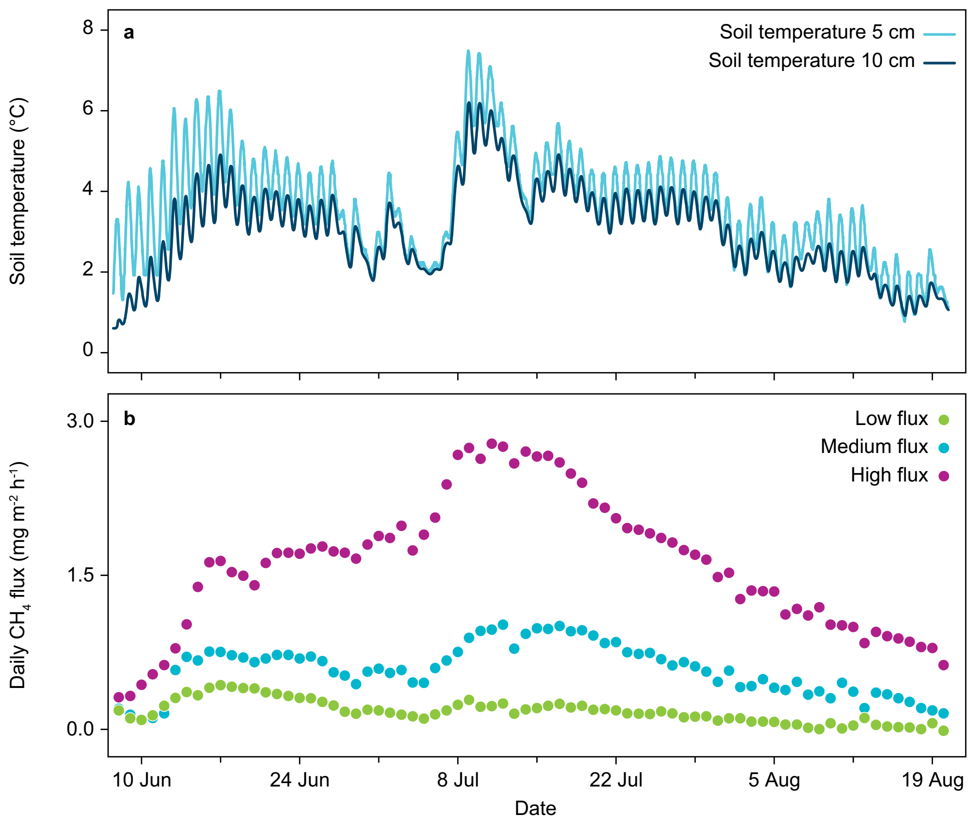


Figure 2.14 Soil temperature (a) and mean daily methane (CH_4) flux (b) 8 June – 20 August 2013 from three different flux groups measured at the fen site.

a moisture gradient. The variation in CH_4 flux between individual chambers was regulated by vegetation density and composition. Presence of vascular plants, especially *Eriophorum scheuchzeri*, appeared to exert great control on this variation. Low emissions from the least moist chambers were primarily ascribed to low substrate availability and quality, as a result of low plant productivity. In general, the findings in Skov (2014) point towards the importance of assessing drivers of CH_4 exchange in an integrative manner, by combining both environmental and biotic controls.

Eddy covariance measurements

The land-atmosphere exchange of CO_2 is measured using the eddy covariance technique in two sites in Zackenberg: one located in a *Cassiope* heath site (MM1) where measurements have been conducted since 2000, and one located in a wet fen area (MM2) where measurements have been conducted since 2007. The heath site instrumentation consists of a 3D sonic anemometer (Gill R3) and a closed-path CO_2 and H_2O gas analyser (Licor-7000). See Klitgaard and Rasch (2008) and Rasch and Caning (2003) for further details on the heath site instrumentation. The fen site instrumentation was upgraded during 2011 to include a 3D sonic anemometer (Gill HS) and an enclosed-path CO_2 and H_2O gas analyser (Licor-7200); see Jensen (2012) for more details.

The temporal variation in the mean daily net ecosystem exchange of CO_2 (NEE) and air temperature during 2013 for the heath and fen sites is shown in figures 2.15 and 2.16 and tables 2.10 and 2.11. NEE refers to the sum of all CO_2 exchange processes; including photosynthetic CO_2 uptake by plants and plant and microbial respiration. The CO_2 exchange is controlled by meteorological conditions, mainly temperature and photosynthetic active radiation (PAR), along with the amount of biomass and soil moisture content. The sign convention used in figures and tables is the standard for micrometeorological measurements; fluxes directed from the surface to the atmosphere are positive whereas fluxes directed from the atmosphere to the surface are negative.

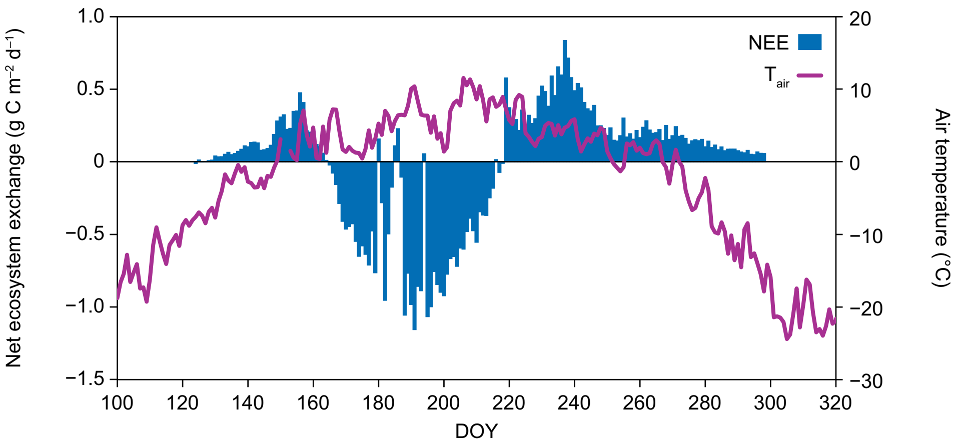


Figure 2.15 Daily net ecosystem exchange (NEE) and air temperature (T_{air}) measured at the heath site (MM1) in 2013.

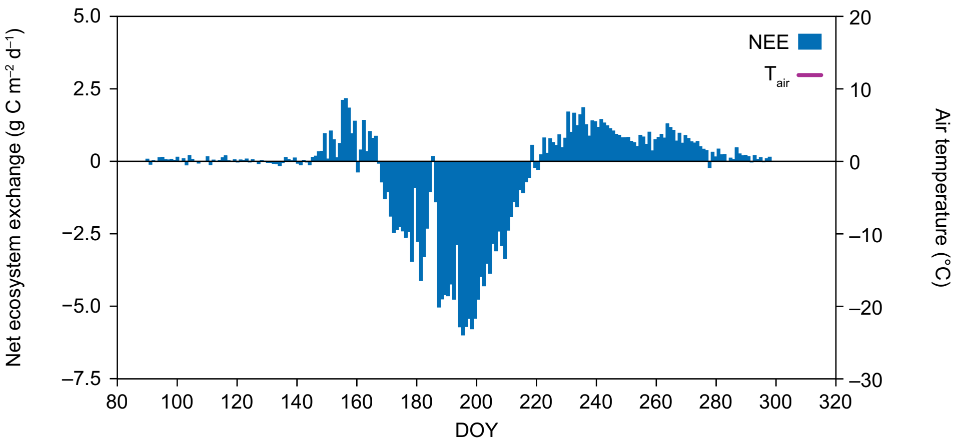


Figure 2.16 Daily net ecosystem exchange (NEE) and air temperature (T_{air}) measured at the fen site (MM2) in 2013.

Table 2.10 Summary of the CO_2 exchanges 2004-2013 at the heath site (MM1). Note that the measuring period varies from year to year.

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Measurements start	3 Jun	21 May	28 May	27 May	30 Mar	16 May	5 May	3 May	26 Apr	1 May
Measurements end	28 Aug	25 Aug	27 Aug	28 Oct	28 Oct	22 Oct	31 Oct	16 Aug	29 Oct	26 Oct
Start of net uptake period	23 Jun	8 Jun	8 Jul	16 Jun	6 Jul	13 Jun	1 Jul	26 Jun	11 Jul	14 June
End of net uptake period	16 Aug	16 Aug	23 Aug	19 Aug	20 Aug	15 Aug	14 Aug	15 Aug	22 Aug	6 Aug
NEE for measuring period ($g C m^{-2}$)	–13.2	–37.9	–24.9	–28.2	–11.2	–11.1	5.0	–23.0	–4.6	–0.7
NEE for net uptake period ($g C m^{-2}$)	–24.6	–38.1	–28.9	–37.8	–32.0	–23.1	–26.8	–31.5	–28.9	–26.8
Max. daily accumulation ($g C m^{-2} d^{-1}$)	–1.14	–1.40	–1.11	–1.32	–1.30	–0.97	–1.14	–0.97	–1.11	–1.14

Table 2.11 Summary of the CO_2 exchanges 2007-2013 at the fen site (MM2). Note that the measuring period varies from year to year.

Year	2007	2008	2009	2010	2011	2012	2013
Measurements start	20 Sep	10 Apr	31 Jul	9 May	7 May	29 Aug	1 Apr
Measurements end	19 Oct	30 Aug	13 Oct	1 Nov	25 Oct	26 Oct	25 Oct
Start of net uptake period	–	10 Jul	–	–	26 Jun	–	17 Jun
End of net uptake period	–	22 Aug	16 Aug	16 Aug	15 Aug	–	9 Aug
NEE for measuring period ($g C m^{-2}$)	9.8	–65.8	3.5	–73.5	–80.5	37.1	–76.3
NEE for net uptake period ($g C m^{-2}$)	–	–94.6	–	–	–129.9	–	–149.0
Max. daily accumulation ($g C m^{-2} d^{-1}$)	–	–4.03	–	–5.15	–4.49	–	–5.99

Heath site

In 2013, eddy covariance CO_2 flux measurements at the heath site (MM1) were initiated 1 May and lasted until 26 October (figure 2.15). When measurements began, the heath was covered by a thin layer of snow, amounting to approximately 0.1 m. During the cold, snow-covered period in late April and in May, CO_2 fluxes were low, below 0.5 $g C m^{-2} d^{-1}$. Maximum spring net CO_2 emission occurred 5 June, amounting to 0.48 $g C m^{-2} d^{-1}$. As the vegetation developed during July, the photosynthetic uptake of CO_2 started, and 14 June the heath ecosystem switched from being a source to a sink for atmospheric CO_2 on a daily basis. Together with 2005 and 2009, this is the earliest start of the net uptake period on record, likely related to the early timing of snowmelt.

The period with net CO_2 uptake ended 6 August, which is the earliest end of net uptake period on record. The onset of the uptake period varies from year to year due to timing of snowmelt. The end of the uptake period is more stable as it is mainly governed by fading solar radiation. The accumulated CO_2 uptake during the uptake period in 2013, –26.8 $g C m^{-2}$, was close to the average (–27.6 $g C m^{-2}$). Also, the maximum diurnal CO_2 uptake (–1.16 $g C m^{-2} d^{-1}$, measured 10 July) was close to the mean of all years (–1.14 $g C m^{-2} d^{-1}$).

By 6 August, ecosystem respiration exceeded gross primary production and the heath ecosystem returned to being a net source for atmospheric CO_2. In the beginning of this period, soil temperatures remain comparably high, allowing decomposition processes to continue at a decent rate. The highest autumn daily emission was measured 25 August (0.84 $g C m^{-2} d^{-1}$). When air temperature fell below 0 °C in late September daily NEE decreased, and at the end of the measuring period daily NEE was close to zero. During the entire measuring period (178 days), the net CO_2 budget amounted to –0.7 $g C m^{-2}$. Taking the rest of the year into account when no measurements were conducted and when small but consistent CO_2 emissions can be expected; the Zackenberg heath likely constituted a net source for atmospheric CO_2 during 2013.

Fen site

In autumn 2012, when the Zackenberg Research Station was left unmanned, the eddy covariance system in the fen (MM2) was for the first time allowed to continue to run unattended. It was powered by solar panels, fuel cells and car batteries. Unfortunately, the fuel cells broke down during the course of early winter, and as such acquired data from the eddy covariance system are afflicted by long periods with missing data. However, the solar panels slowly woke up the system in late February/early March. Here, we report data from 1 April 2013 until 25 October 2013 (figure 2.16). In autumn 2013, a wind mill replaced the fuel cells in order to improve the power supply during winter.

During the cold period in April-May, when air temperatures were generally below 0 °C, CO_2 fluxes remained close to zero. As temperatures turned positive in late May, CO_2 fluxes increased and peaked at 2.16 g C m^{-2} d^{-1} 6 June. On 17 June, the fen ecosystem switched from being a source for atmospheric CO_2 to a sink. The period with net diurnal CO_2 uptake lasted until 9 August; and during this period the fen absorbed -149.0 g C m^{-2}, which is more than the two previous years that covered the entire uptake period (2008 and 2012). Maximum daily uptake amounted to –5.99 g C m^{-2} d^{1}; a figure that is also higher than for previous years.

After the net uptake period had ended, CO_2 fluxes remained relatively high (around 1 g C m^{-2} d^{-1}) until air temperatures fell below 0 °C in late September. Maximum daily emission after the net uptake period (1.85 g C m^{-2}) was detected 24 August. During the entire period for which data is presented in this report (208 days; 1 April – 25 October), the CO_2 budget of the fen ecosystem amounted to –76.3 g C m^{-2}.

The growing season daily uptake rates as well as shoulder seasons daily emissions are generally higher in the fen site compared to the heath site. This is because of denser vegetation with higher leaf area index in the fen site, allowing for higher CO_2 uptake per area unit.

2.6 Geomorphology

Coastal geomorphology

In 2008, the cliff top along the northern site of the active delta lobe was measured, while the shoreline has been measured the last four years (figure 2.1).

The shoreline at the river delta showed a rapid decrease from 2008 towards 2010. Most of the protruding glacial cliff was eroded and a small island remained on the delta plain. The small island eroded away in 2012. The lines from 2010 and 2012 are almost similar. The line from 2011 was recorded after the first snow and it was not possible to see the high-water mark on the beach. From 2011 to 2012, the shoreline at the delta mouth has eroded up to several metres. The coast line measured in 2013 (see figure 2.17) is almost identical to the line from 2012 and no major erosion has happened since the big river burst in 2012 (Jensen et al. 2013).

Figure 2.17 Delta- and coastal cliff line measured by DGPS in 2008 (green line), 17 October 2010 (blue line), 12 October 2011 (purple line), 28 September 2012 (red line) and 10 September 2013 (dotted yellow line) on an aerial photo from 8 August 2000.

3 Zackenberg Basic

The GlacioBasis programme

Michele Citterio, Marek Stibal, Signe Hillerup Larsen, Filippo Calí Quaglia and Andreas Ahlstrøm

Since 2008, the GlacioBasis monitoring programme at Zackenberg carries out detailed glaciological observations to monitor the mass balance, near-surface weather, surface energy balance and surface ice velocities of A.P. Olsen Ice Cap and its outlet glacier in the river Zackenberg basin (figure 3.1). The A.P. Olsen Ice Cap is located at 74° 39′ N, 21° 42′ W. The summit of the Ice Cap reaches an elevation of 1425 m and the terminus of the outlet glacier contributing to the river Zackenberg basin is at 525 m. Zackenberg Research Station is located SE of the site, approximately 35 km downriver from the glacier terminus. The most direct access to the glacier terminus is through Store Sødal.

The severe scarceness of glacier mass balance measurements from the local glaciers and ice caps surrounding the Greenland Ice Sheet, the strong impact that such ice masses are expected to exert on sea level rise in the present century (Machguth et al. 2013), and the particularly marked warming expected to take place in the Arctic (IPCC 2013) highlight the scientific relevance of GlacioBasis monitoring tasks. The monitoring data are being used for modelling the surface energy balance and the glacier mass budget, and for assessing the sensitivity to future climate change scenarios of local glaciers and ice caps in this region.

In order to measure winter accumulation, fieldwork must be carried out during springtime, immediately before the onset of snowmelt. This timing is also required for snowmobile use, which are the only practical mean to reach the glacier and transport the required equipment and instrumentation. Fieldwork must be carried out every year in order to maintain the stakes network operational, to service the automatic weather stations (AWS) on the glacier, and to carry out the Differential GPS (DGPS) and snow radar surveys.

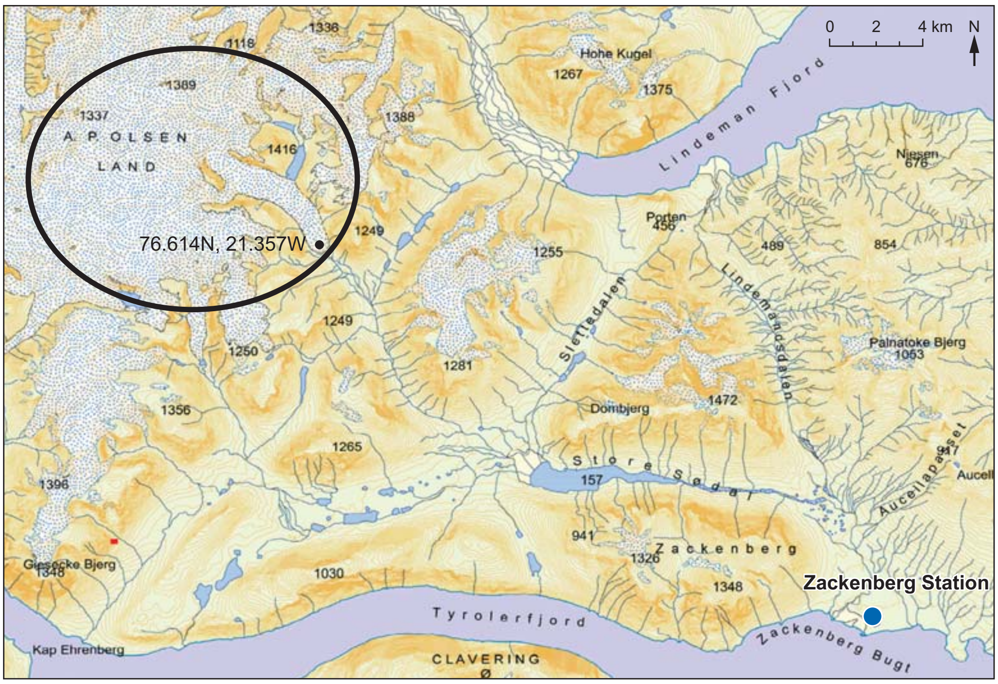


Figure 3.1 Map of the Zackenberg area, with A.P. Olsen Ice Cap in the north-western corner of the map. The main investigation area is marked by the circle. Geological Survey of Denmark and Greenland (GEUS), Copenhagen, Denmark.

3.1 Overview of fieldwork in 2013

In 2013, the complete GlacioBasis programme could be carried out successfully, with the exception of radar snow surveys, which could not be performed due to ground conditions. However, snow depths at the ablation stakes have been measured. Snow cover on the ground was very limited, both on the glacier and along all approach routes from Zackenberg Research Station. It took three days to find a feasible access route for the snow scooters, but the terminal moraine proved impassable. The work on the glacier was only possible thanks to the logistical support of Jørgen Skafte of Zackenberg Research Station using the Argo all-terrain vehicle. Travelling to and from the glacier was minimized by setting up a tent camp at the terminus of the glacier together with the Austrian colleagues from the Zentralanstalt für Meteorologie und Geodynamik (ZAMG, Vienna) studying the glacier dammed lake.

All existing ablation stakes were revisited, measured and re-drilled if needed, with the exception of stake number seven, which again in 2013 could not be approached due to crevasses and is now permanently abandoned. Snow pits were dug and density measured at locations over the altitudinal range of the Ice Cap.

The three AWS were serviced, data retrieved and the sensor recalibration plan implemented. All stations were found in good conditions and left in full working order. At all elevations the snow cover was significantly thinner than in previous years, with extensive areas of exposed bare ice on the glacier tongue. At the summit AWS only a few decimetres of snow was observed.

A three metres deep shallow firn core was drilled using a Kovacs four inch corer borrowed from Professor Georg Kaser (University of Innsbruck, Austria), and delivered frozen in Copenhagen to the cold laboratory facilities of the Centre for Ice and Climate (University of Copenhagen). Surface ice samples were also collected from the surroundings of the lower (AWS1) and intermediate (AWS2) weather stations by Marek Stibal (GEUS) as part of investigations in the feedbacks between microbiological activity during the melt season and the darkening of the ice surface. Dual frequency GPS surveys were carried out in static mode at the sites of the ablation stakes in order to track surface elevation and velocity by comparison with the measurements taken in 2012. The master reference station was setup at the forefront of the glacier, occupying a temporary, unsurveyed position. The precise coordinates of this reference station were later determined to centimetric accuracy by precise post-processing (PPP). The positions of the stakes were obtained by carrier phase static differential post-processing.

Michele Citterio (GEUS, GlacioBasis) and Marek Stibal (GEUS, GlacioBasis) took part in the fieldwork.

3.2 Automatic Weather Stations

The GlacioBasis programme operates one larger automatic weather station (AWS) and two smaller stations deployed on the glacier to obtain in situ time series of physical parameters describing the weather at the glacier surface. The main GlacioBasis AWS was deployed in March-April 2008 on A.P. Olsen Ice cap (AWS1 in this report). AWS1 is the prototype unit of all the current GEUS glaciological weather stations in Greenland and has proved very reliable, having now completed the sixth year of uninterrupted operation. Technical and design details are provided in Citterio (2009). In 2013, planned sensor replacement for recalibration was carried out. The aluminium stake assembly carrying one of the two sonic rangers had collapsed but it could not be re-established due to the limited availability of the Argo vehicle on the glacier. Ablation is also measured at AWS1 by an ablation monitor (Fausto et al. 2012) installed in 2012, so the temporary loss of the sonic ranger is not critical.

AWS2 required some maintenance to the frame supporting the ice ablation sonic ranger in addition to planned sensor replacement. Ongoing surface energy and mass balance modelling by Signe Hillerup Larsen at GEUS (Larsen, 2013) indicates that the pattern of snow depths over wide parts of the glacier tongue is rather unusual, exhibiting an inverse altitudinal gradient in the lower tongue during most years which significantly impacts the surface albedo and consequently the surface energy balance. As a part of the GEM 2011-2015 strategy, AWS2 was in 2012 equipped with radiometers and tilt

Figure 3.2 Snow cover at the lower station AWS1 was almost absent and bare ice is visible next to the Argo all-terrain vehicle. Marek Stibal can be seen in the background collecting surface ice samples. Photo: Michele Citterio (Copyright GEUS).

sensors to measure the surface radiative energy fluxes in this part of the upper ablation area. The 2012 snow cover was significantly thicker than average, and the thin 2013 snow cover provide a much needed comparison to assess the inter-annual variability. Together with the AWS data and ablation stake measurements that will be conducted next May 2014, the two contrasting 2012 and 2013 season will allow to move forward with the mass and energy balance modelling.

AWS3 was found in good conditions and scheduled replacement of sensors with freshly calibrated units was carried out. GlacioBasis uses the same recalibration plan developed for PROMICE (Ahlstrøm et al. 2009). Following the field visit, satellite data transmissions indicate that all stations are working properly. AWS3 automatically switched to low-power operation in mid-winter, suspending satellite data transmission to save battery power, but it resumed transmissions regularly in early 2014 with no data gap.

During data validation and calibration, data were calibrated based on the manufacturer's calibration report. The calibration factors are traced to the corresponding devices through the device serial number using the same Glaciobase database used at GEUS to handle the sensors inventory for PROMICE. Details on Glaciobase are provided by Ahlstrøm et al. (2009) and are not repeated here. Validation of the data is carried out using the same procedures established for PROMICE; again, details on this are provided by Ahlstrøm et al. (2009) and are not repeated here.

Detailed information on each AWS and a selection of the observed data is shown below, where plots show the entire availability of data starting from the establishment of the first two AWS's in late March 2008.

The AWS1 station

Description: AWS1 – A.P. Olsen Main AWS (centreline, lower tongue).
Coordinates: 74° 37.5′ N, 21° 22.55′ W, elevation (WGS84): 660 m.
Measured parameters: Barometric pressure, aspirated T_{air}, aspirated RH_{air}, wind speed, wind direction, downwelling SW, upwelling SW, downwelling LW, upwelling LW radiation, T of LW radiometer, ice ablation, ice level, snow level, eight-levels thermistor string, two axes station tilt, GPS position, diagnostics, experimental sensors (variable from year to year, currently a passive radiation shield with a second Rotronics temperature and humidity probe identical to the one in the aspirated radiation shield).
Time series: Uninterrupted from 29 March 2008 to today for all sensors except the sonic rangers, whose support stake often fail toward the end of the ablation season.
Current availability: All transmitted data (hourly summer/3-hourly winter); 10 minutes from flash card between 29 March 2008 and 24 April 2013.

AWS1 has been working without interruption since the day it was set up 29 March 2008, and satellite telemetry delivers near real-time data. As a site and station especially well-suited to technical experiments and testing of new devices, the ongoing experiment comparing a pas-

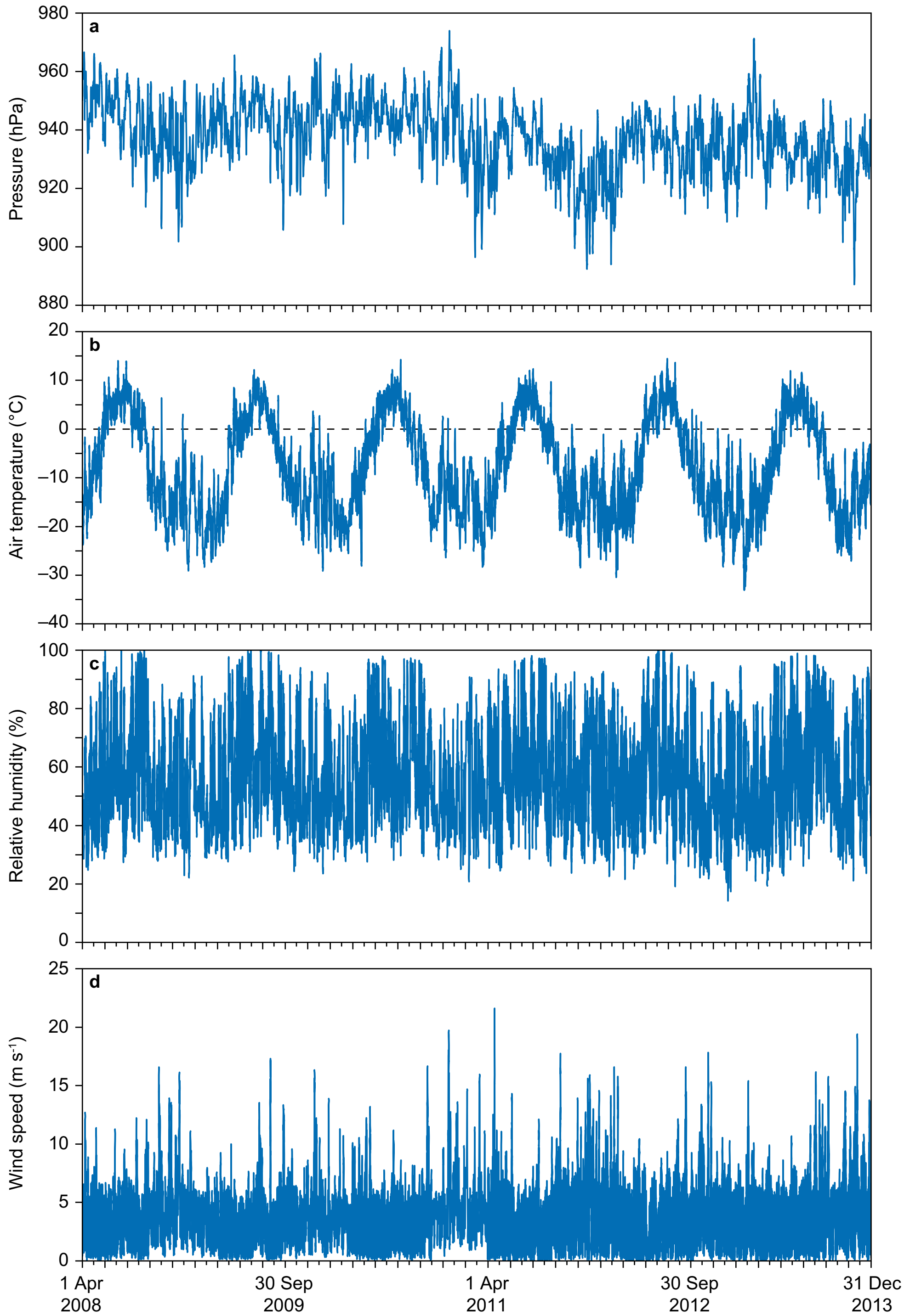


Figure 3.3 The complete available time series of selected parameters at AWS1: a) barometric pressure, b) air temperature, c) relative humidity and d) wind speed.

sive Campbell Scientific radiation shield against the aspirated Rotronics radiation shield that is used in all other GEUS glacier AWS is being continued. Complete time series of barometric pressure, air temperature, relative humidity and wind speed are shown in figure 3.3a through 3.3d, respectively.

The AWS2 station

Description: AWS2 – A.P. Olsen small AWS (centreline, middle tongue, just upflow of lake and lateral glacier confluence).

Coordinates: 74° 38.6′ N, 21° 28.2′ W, elevation (WGS84): 880 m.

Measured parameters: Aspirated T_{air}, aspirated RH_{air}, wind speed, wind direction, ice level, snow level, GPS position, downwelling SW, upwelling SW, downwelling LW, upwelling LW radiation, T of LW radiometers and two axes station tilt diagnostics.

Time series: Uninterrupted from 31 March 2008 to today for all sensors except the sonic rangers, whose support stake often fail toward the end of the ablation season.

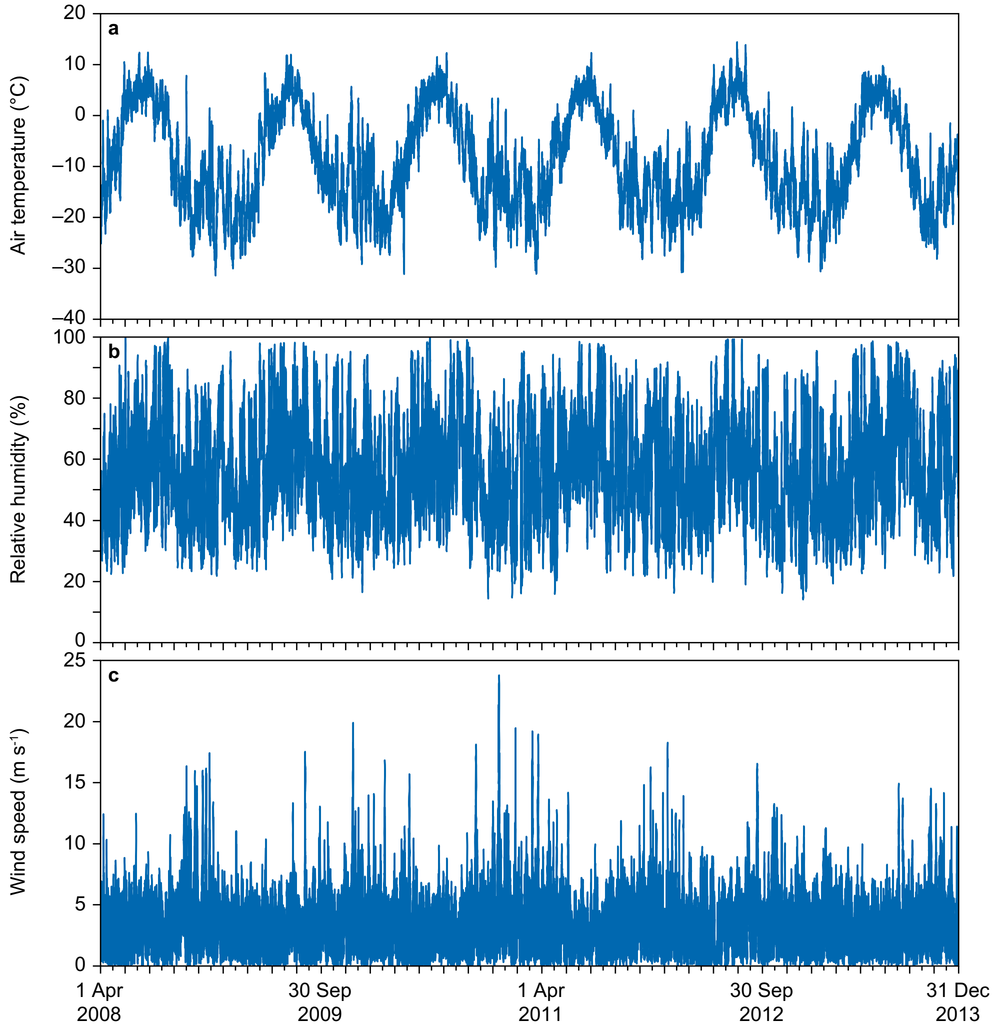


Figure 3.4 The complete available time series of selected parameters at AWS2: air temperature (a), relative humidity (b) and wind speed (c).

Current availability: 10 minutes from flash card from 31 March 2008 to 22 April 2013. There is no satellite data telemetry; therefore data is only retrieved once a year in the field.

This AWS is a smaller version of AWS1 not equipped with satellite transmission, and data retrieval in the field is required for this station. The metal frame supporting the sonic ranger measuring ice ablation was found in unstable conditions. The frame was secured, data downloaded and the scheduled recalibration plan was implemented. Air temperature, relative humidity and wind speed are shown in figure 3.4a through 3.4c, respectively.

The AWS3 station

Description: AWS3 – A.P. Olsen Summit (at the wide open flat just SSW of A.P. Olsen Summit).
Coordinates: 74° 38.9′ N, 21° 39.1′ W, elevation (WGS84): 1475 m.
Measured Parameters: Aspirated T_{air}, aspirated RH_{air}, wind speed, wind direction, downwelling SW, upwelling SW, downwelling LW, upwelling LW, sensor T of the LW radiometer, ice and snow level, eight-levels thermistor string, two axes station tilt, GPS fix, diagnostics.
Time series: From 6 August 2009 to 19 October 2010, for all sensors except the sonic rangers which had intermittent problems, with a four days gap for unknown reasons just before the revisit 11 May 2010. In winter 2010 and 2013 the station entered low power operation suspending satellite data transmissions, but without data gaps after data stored locally on the memory card was retrieved during the field visits.
Current availability: 10 minutes from flash card from 6 August 2009 to 20 April 2014, then hourly/summer and three hourly/winter until next revisit.
Notes: Fitted for extension with one additional thermistor string.

This AWS was setup by helicopter 6 August 2009. It was initially equipped with a subset of the sensors of AWS1 and

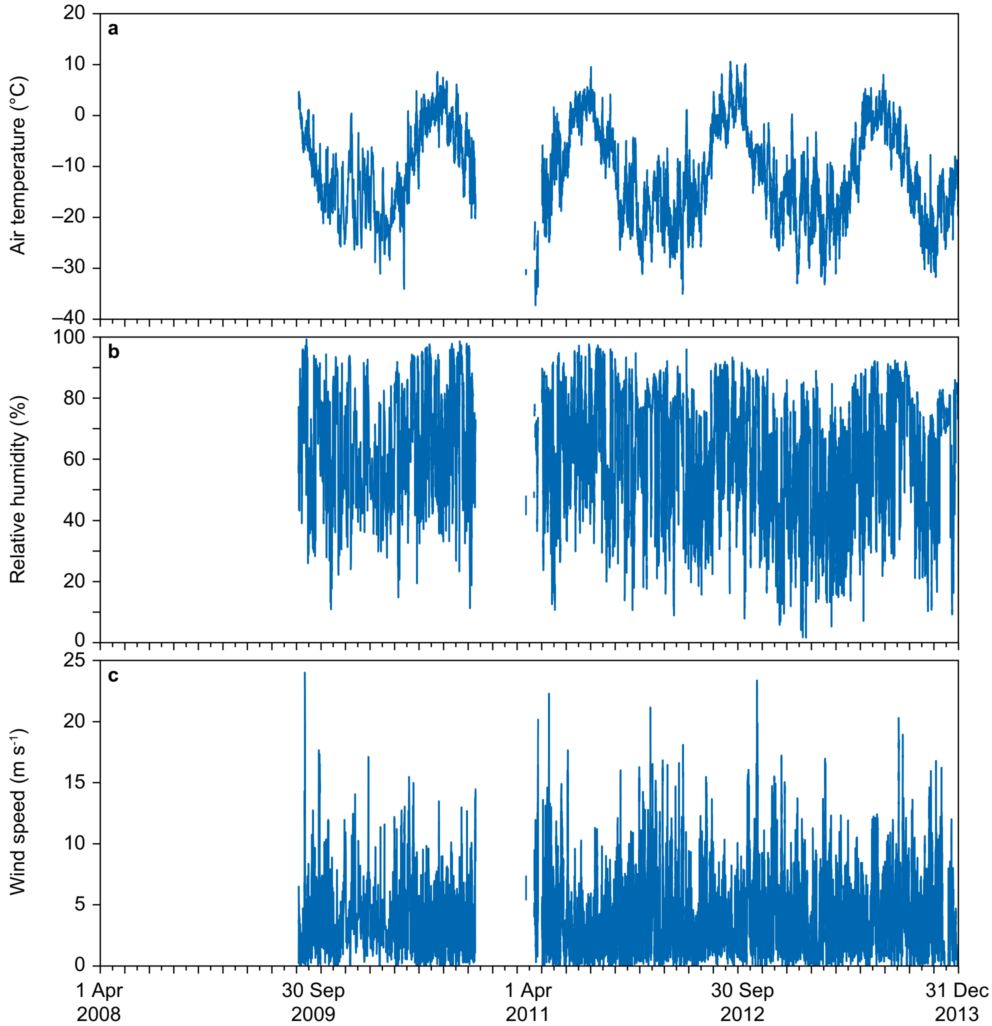


Figure 3.5 The complete available time series of selected parameters at AWS3: air temperature (a), relative humidity (b) and wind speed (c).

since 2012 with a full sensors suite. The GPS receiver in this station is faulty and it will be replaced during the 2014 field visit. Being close to the summit of the Ice Cap, this station is not moving significantly. Figure 3.5a through 3.5c show air temperature, relative humidity and wind speed from AWS3.

3.3 Ablation stakes network

A network of ablation and surface velocity stakes distributed along the central flow line was established in spring 2008 on the outlet glacier of the A.P. Olsen Ice Cap and along three transects at elevations of approximately 675, 900 and 1300 m a.s.l. (figure 3.6). Since May 2010 one more stake is maintained very close to the terminus (stake 1, figure 3.6) in order to better cover the area strongest ablation. Accurate location of the stakes is provided in the 2012 Annual Report (Jensen et al. 2013).

Surveying the network of ablation stakes is a core task of GlacioBasis, because it provides a direct measurement of the glacier mass balance, which is central to the entire programme. Ablation stakes are six m long metal rods drilled into the ice and measured periodically to quantify the amount of water lost to ablation. Stakes are distributed over the glacier surface with the primary aim to cover the entire elevation range of the glacier, because glacier mass balance shows the strongest gradient with elevation. Stakes are also arranged in transects at roughly the same elevation in order to capture the lateral variability moving out from the centreline of the glacier, due e.g. to shading and long wave radiation from the surrounding rock walls. Figure 3.6 provides an overview and map of the investigated outlet glacier of the A.P. Olsen Ice Cap.

3.4 Differential GPS surveys

Surface ice velocities are being monitored by repeated precision survey of ablation

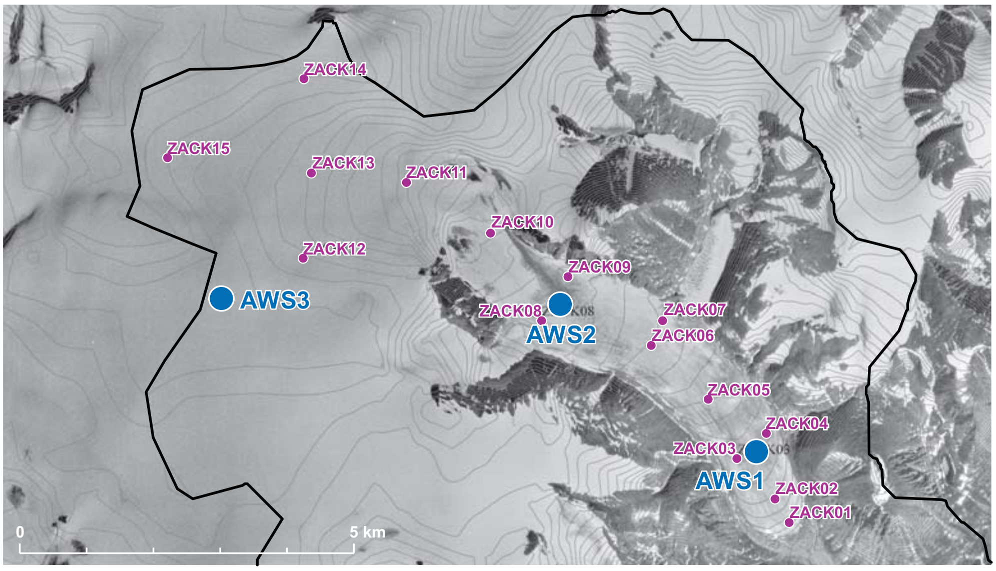


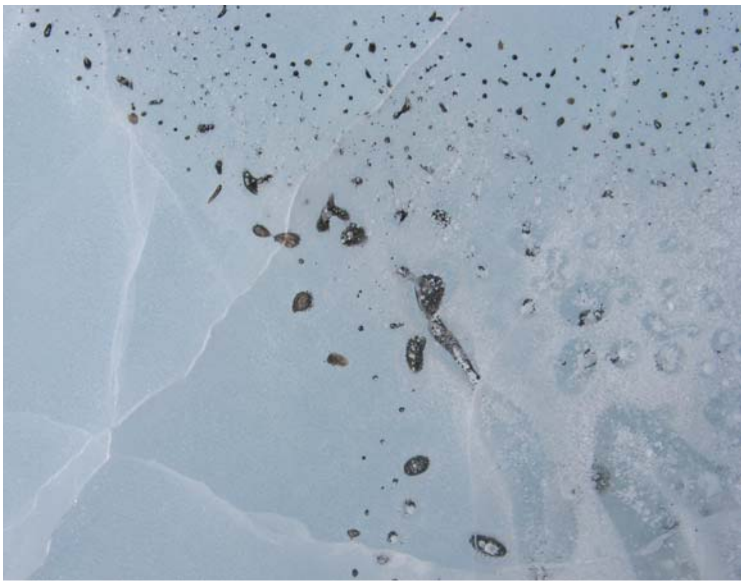
Figure 3.6 – Orthophotograph of the investigated outlet glacier with the position of ablation stakes (red dots) and AWSs (blue dots).

stake positions. The GPS phase recordings are post-processed as individual baselines from the master station located at the glacier terminus and the rover station positioned at the site of each ablation stake. In 2013, additional measurements were recorded to assess the suitability of a nunatak in the upper part of the Ice Cap as a site for a future permanent GPS station in collaboration with ZAMG (Vienna) within the ongoing cooperation to study the A.P. Olsen glacier dammed lake. The coordinates of the master station were determined for each survey day by the PPP (Precise Post-Processing) method, and the measurement baselines follow the layout illustrated in the 2012 Annual Report (Jensen et al. 2013).

3.5 Shallow firn coring and ice sampling

A.P. Olsen Ice Cap is the only peripheral ice cap in Greenland with ongoing glaciological monitoring including extensive radar surveys of seasonal snow depth, sub-glacial bedrock topography, near-surface weather at several automatic weather stations, and continuous measurements of subsurface temperature profiles in ice and firn by means of thermistor stings. As such, it is a potentially interesting targets for firn and ice coring, and for studies of surface processes. In 2013, a shallow firn core was drilled next to the site of the AP. Olsen summit weather station (AWS3). The core was drilled within a single day using a Kovacs four inch corer able to drill firn and ice to a maximum depth of three metres. The core was immediately measured, cut and packaged on site and subsequently kept frozen until delivery to the cold laboratory facilities at Centre of Ice and Climate, University of Copenhagen. The core will be sampled and stable isotopes analysed to assess the potential of A.P. Olsen Land as a source of past climate information. Surface ice samples from the general surroundings of AWS1 and AWS2 have also been collected by Marek Stibal at the sites of frozen melt water ponds and cryoconite holes from the previous summer season (figure 3.7). These samples will be part of an ongoing Greenland-wide study to quantify the feedbacks between biological activity in the melt water ponds darkening the surface of the ice, and increased solar radiation absorption.

Figure 3.7 Dark material at the glacier surface and in frozen cryoconite holes from the 2012 melt season, photographed and sampled in 2013. Photo: Marek Stibal (Copyright GEUS).



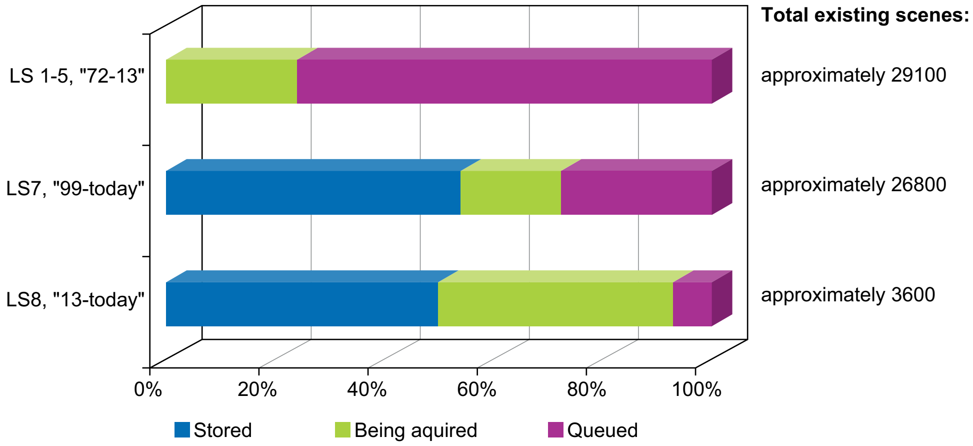


Figure 3.8 Status of the ongoing Landsat imagery collection and archiving for Greenland peripheral glaciers and ice sheet margin regions. Archival of scenes covering A.P. Olsen Ice Cap is complete.

3.6 Optical remote sensing

The seasonal evolution of the transient snow line has a large impact on surface mass and energy balance due to the strong albedo contrast between snow and ice. Modelling by Signe Hillerup Larsen at GEUS (Larsen, 2013) and *in situ* observations during the past GlacioBasis campaigns indicate that the pattern of snow accumulation significantly deviates in most years from a simple altitudinal gradient. Optical remote sensing can provide snapshots of the transient snow line during the ablation season, and the systematic collection of past and current Landsat and ASTER images was initiated. This is being carried out as a joint GlacioBasis – PROMICE activity at GEUS, aimed at creating a spatially-enabled database of remote sensing and mapping information spanning the last four decades, with the contribution of Filippo Calí Quaglia from University of Torino (Italy). Data acquisition of the complete Landsat archive over the A.P. Olsen area was completed in 2013, while the remaining areas of Greenland occupied by local glaciers and the margin of the ice sheet is ongoing (figure 3.8 gives a status overview for all Greenland glacierized regions updated to beginning of 2014).

A spatial database based on the open source PostGIS application is being implemented to simplify the analysis of the large amount of data, and it may support a future new outreach product distributed through PolarPortal (www.polarportal.org).

4 Zackenberg Basic

The BioBasis programme

Lars Holst Hansen, Jannik Hansen, Palle Smedegaard Nielsen, Jakob Humaidan, Kirsten S. Christoffersen and Niels Martin Schmidt

This chapter reports the 2013 field season of BioBasis. The BioBasis programme at Zackenberg is carried out by Department of Bioscience, Aarhus University, Denmark. BioBasis is funded by the Environmental Protection Agency as part of the environmental support programme Danish Cooperation for Environment in the Arctic (DANCEA). The authors are solely responsible for all results and conclusions presented in the report, which do not necessarily reflect the position of the Environmental Protection Agency.

Please refer to previous Zackenberg Annual Reports for presentation of data covering the earliest years of monitoring. Detailed information on the BioBasis methods and updated sampling protocols are available at the Zackenberg web site (www.zackenberg.dk).

The 2013 BioBasis field team consisted of Palle Smedegaard Nielsen (day 128-184), Jannik Hansen (day 149-219), Lars Holst Hansen (day 177-294), Jakob Humaidan (day 191-271), and Niels Martin Schmidt (276-303).

Table 4.1 Inter- and extrapolated date of 50 % snow cover 2003-2013 for white arctic bell-heather Cassiope tetragona, *mountain avens* Dryas integrifolia/octopetala, *arctic poppy* Papaver radicatum, *arctic willow* Salix arctica, *purple saxifrage* Saxifraga oppositifolia *and moss campion* Silene acaulis.

Plot	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Cassiope 1	157	<155	143	164	155	164	138	150	147	168	<129
Cassiope 2	164	168	158	183	167	174	145	164	153	182	145
Cassiope 3	158	159	148	179	158	172	140	164	159	176	135
Cassiope 4	158	159	158	174	164	174	148	167	161	178	141
Dryas 1	155*	<154	<140	150*	<145	147	<135	<142	<135	153	132
Dryas 2/*Salix* 7	173	173	168	192	170	182	157	174	168	187	151
Dryas 3	157	<155	<140	151	<145	147	136	<142	<136	153	<129
Dryas 4	151*	<153	<140	164	152	162	135	<142	150	168	126*
Dryas 5	157	<153	<140	177	<145	152	<135	142	<136	161	130
Dryas 6/*Papaver* 4	170	173	165	191	164	184	149	170	169	184	144
Papaver 1	163	166	152	179	162	169	139	162	146	181	136
Papaver 2/*Salix* 5	172	163	158	183	161	178	149	166	160	178	148
Papaver 3	165	160	158	174	163	174	148	167	161	177	142
Salix 1	151*	<155	<140	145*	<145	137	<135	<142	<135	148	<129
Salix 2	165	161	156	178	160	169	148	162	159	176	146
Salix 3	153*	<155	138*	160	151	163	<135	146	145	167	<129
Salix 4	164	157	150	165	154	161	147	158	157	162	130
Salix 6		173	166	186	165	182	149	169	166	185	148
Saxifraga/*Silene* 1	152*	<154	<140	<146	<145	<131	<135	<142	<135	147	<129
Saxifraga/*Silene* 2	151*	<154	<140	<146	<145	<131	<135	<142	<135	152	<129
Saxifraga/*Silene* 3	152*	<154	128*	158	152	145	<135	<142	<136	158	128*
Silene 4	170	170	163	186	164	176	150	167	165	181	146

*Denote extrapolated dates

4.1 Vegetation

The weekly records of snow cover, plant flowering and reproduction were conducted by Palle Smedegaard Nielsen, Jannik Hansen, Lars Holst Hansen and Jakob Humaidan. No gas flux measurements were conducted for the BioBasis Programme and no pinpoint analyses and fluorescence measurements were carried out in 2013.

Reproductive phenology and amounts of flowering

The 2013 BioBasis field season began 8 May (day 152). Snowmelt was very early, and eight of 22 plant phenology plots had less than 50 % snow at the first check 9 May (day 129). Considering the small amount of snow, it is possible that some or all of these plots did not have more than 50 % snow cover during the winter. However, for two of these, dates of 50 % were extrapolated. Twenty plots had dates of 50 % snow cover earlier than the earliest for previous years, and two of the 22 had dates of 50 % snow cover as early as the earliest hitherto recorded (table 4.1). The early snowmelt resulted in earlier than average 50 % flowering in all of the 28 plots, when compared to previous years (table 4.2). In 15 of the 28 plots the 50 % flowering was similar to or earlier than the previously earliest recordings. Two *Salix* plots had fast catkin development from a total empty plot to having more

Table 4.2 Inter- and extrapolated date of 50 % open flowers (50/50 ratio of buds/open flowers) 2003-2013 for white arctic bell-heather Cassiope tetragona, *mountain avens* Dryas integrifolia/octopetala, *arctic poppy* Papaver radicatum, *arctic willow* Salix arctica, *purple saxifrage* Saxifraga oppositifolia *and moss campion* Silene acaulis. **Denote interpolated dates based on less than 50 buds + flowers. #Denote a DOY between 154 and 161.*

Plot	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Cassiope 1	178	175	167	185	178	186	173	176	172	187	167
Cassiope 2	184	187	173	201	186	193	180	186	176	198	173
Cassiope 3	183	182	173	200	185	194	178	184	183	195	173
Cassiope 4	186	185	183	200	186	195	183	190	185	195	176
Dryas 1	181	173	164	177	173	172	170	170	170	173	171
Dryas 2	200	200	198	215	192	204	188	200	193	207	183
Dryas 3	180	175	164	180	177	174	175*	174	171	176	177*
Dryas 4	174	174	164	187	178	186	173	172	172	190	171
Dryas 5	179	172	164	172	171	175	172*	172	167	182	171
Dryas 6	198	199	194	214	191	206	185	200	194	207	180
Papaver 1	186	193	185	206	188*	195	184	190*	179*	203*	184*
Papaver 2	189	190	190	208	188	204	185	194	187	203	185
Papaver 3	192	187	187	201	187*	199	186	193	187	200	185
Papaver 4	198	194	194	214	192*	204	186*	197*	194	207*	182
Salix 1	168	156	155	165	161	161	155	162	156	167	157
Salix 2	179	173	165	196	177	187	167	177	174	192	164
Salix 3	166	159	157	174	165	174	152*	161	159	180	<161#
Salix 4	174	173	164	180	170	174	167	174	171	<184	<161#
Salix 5	186	175	164	194	174	193	168	179	174	193	164
Salix 6	–	197	184	200	179	194	171	184	180	197	164
Salix 7	–	187	187	202	182	195	179	186	185	194	170
Saxifraga 1	165	157	144	151	160*	159*	149*	153	144	158*	159
Saxifraga 2	165	157	152	157	158	158	150	157	151*	<155	159
Saxifraga 3	165	<154	146	172	165	159*	146*	161	151	166	159
Silene 1	182	173	165	170	173	172	174	174	172	176	173
Silene 2	185	181	166	182	179	173	184	179	175	175	175
Silene 3	185	172	166	194	179*	173	180	178	172	190	177
Silene 4	201	201	197	194	193	207	187	199	198	208	182

*Denote interpolated dates based on less than 50 buds + flowers. #Denote a DOY between 154 and 161

Table 4.3 Inter- and extrapolated date of 50 % open seed capsules 2003-2013 for arctic poppy Papaver radicatum*, arctic willow* Salix arctica *and purple saxifrage* Saxifraga oppositifolia.

Plot	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Papaver 1	228	232	213	219	212	232	223	211*	203	223*	207	229*	217*
Papaver 2	228	229	215	219	215	234	221	226	206	221	214	225	214
Papaver 3	230	232	218	216	212	223	220	215	212	225	216	226	217
Papaver 4	236*	238*	222	227	220	239*	222*	222*	214*	222*	220	229	213
Salix 1	214	210	214	208	201	219	218	211*	220	223	218	211	214
Salix 2	230	223	215	218	215	231	220	227	218	222	222	233	213
Salix 3	226	217	209	209	206	223	215	225	213*	218	212	228	210
Salix 4	225	224	215	219	210	223	219	225	220	222	221	226	212
Salix 5	–	–	216	220	219	>240	221	229	215	227	222	234	218
Salix 6	–	–	223	223	226	>240	222	234	217	228	229	239	217
Salix 7	–	–	225	223	226	>240	224	234	221	229	232	241	218
Saxifraga 1	220	216	219	205	203	217*	218	195	209*	212	218*	189	>231
Saxifraga 2	226	213	223	209	212	217	216	205	213	214	193	189	214
Saxifraga 3	225	224	221	205	212	225	221	188	215*	218	207	188	215

*Denote interpolated dates based on less than 50 flowers + open capsules

than 50 percent developed catkins on two consecutive checks (one week). Linear extrapolation resulted in an impossible 50 % date before buds had even emerged. In the table 4.2 the maximum value is listed. All but one plant plots had earlier than average dates of 50 % open seed capsules compared to previous years (table 4.3). One *Papaver* and one *Salix* plot had new record early dates and one *Salix* plot had a date equalling the hitherto earliest. In the 2013 season, 29 of 40 categories of flowers or catkins had lower than the average peak number of flowers or catkins hitherto recorded (table 4.4). There were no new maxima but new minima in two *Eriophorum* and two *Papaver* plots.

Vegetation greening

Table 4.5 lists the dates (as day of year – DOY) of the peak NDVI (Normalised Difference Vegetation Index) of 16 of the permanent plots. In all of the 16 tabulated plant plots, peak NDVI was earlier than the average of previous years. In addition, all peak NDVI values from 2013 were below average for all the previous seasons.

Transect NDVI was measured from snowmelt and into the autumn until the ground was covered with snow. Figure 4.1 summarises the NDVI transect data across the 2013 season in three altitude categories. Due to rainy weather in September with additional snowfall only three transects were completed. The different vegetation types had very similar developments in NDVI in all three altitude categories, but the order of the NDVI values for the vegetation types changed with altitude.

Figure 4.1 Mean NDVI from the four main vegetation types (fen, grassland, Salix *heath,* Cassiope *heath) along an altitudinal gradient in Zackenberg during the 2013 season, averaged for three altitude intervals; [0-140], [140-280] and [280-420] m above sea level.*

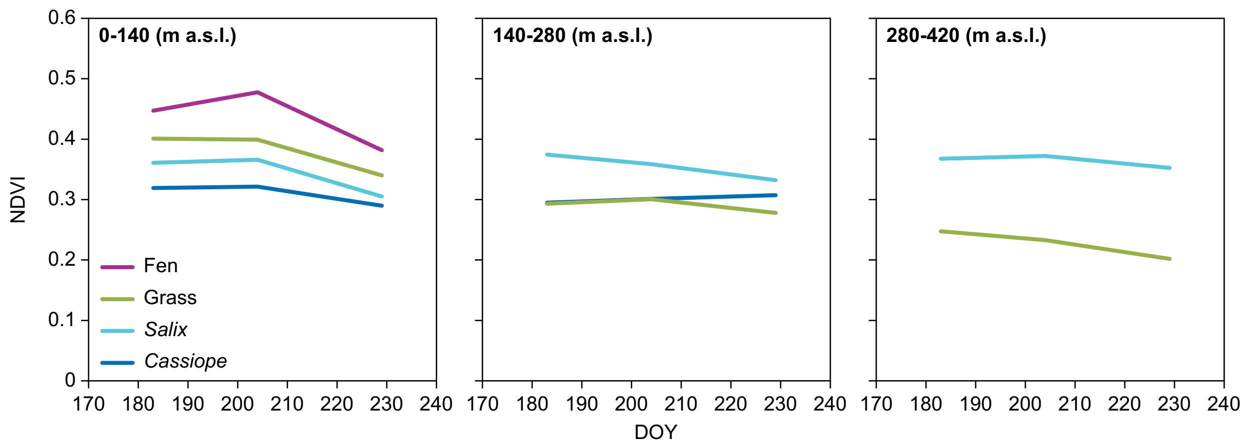


Table 4.4 Area size (m²) and peak pooled numbers of flower buds, flowers (or catkins) and senescent flowers (or catkins) 2003-2013 of white arctic bell-heather Cassiope tetragona, *mountain avens* Dryas integrifolia/octopetala, *arctic poppy* Papaver radicatum, *arctic willow* Salix arctica, *purple saxifrage* Saxifraga oppositifolia, *moss campion* Silene acaulis, *arctic cottongrass* Eriophorum scheuzerii *and 'dark cottongrass'* Eriophorum triste. *Saxifraga *1 had a second flowering peak with a number of 77 buds/flowers.* Erratum*: After revision of the raw data several numbers have been updated compared to previous annual reports.*

Plot	Area	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Cassiope 1	2	851	2080	1392	973	435	1183	233	431	890	799	166
Cassiope 2	3	1001	1745	1203	593	300	958	555	340	1045	1459	689
Cassiope 3	2	817	791	862	432	86	704	256	227	489	490	201
Cassiope 4	3	1189	1274	1856	520	223	1340	437	304	659	615	497
Dryas 1	4	744	444	392	321	147	190	254	334	530	533	288
Dryas 2	60	552	1174	520	521	561	806	395	410	483	401	628
Dryas 3	2	294	273	200	134	90	94	32	129	281	403	43
Dryas 4	6	224	218	144	168	181	141	90	192	279	215	91
Dryas 5	6	589	351	232	123	115	103	51	318	560	571	342
Dryas 6	91	627	1854	880	1324	1144	1606	593	889	1185	1351	955
Papaver 1	105	278	286	207	153	108	80	68	53	84	31	28
Papaver 2	150	564	402	682	416	334	500	341	416	251	365	234
Papaver 3	90	351	221	316	234	236	190	188	138	259	92	123
Papaver 4	91	56	37	68	71	29	71	26	80	96	92	128
Salix 1 mm.	60	1931	1127	375	183	184	2	243	857	207	790	782
Salix 1 ff.	60	2159	1606	386	303	241	3	234	1172	425	1075	961
Salix 2 mm.	300	967	1276	737	654	317	758	304	521	578	697	379
Salix 2 ff.	300	1638	1862	1089	1076	386	506	570	1512	877	1069	397
Salix 3 mm.	36	621	693	285	204	169	492	40	294	194	562	265
Salix 3 ff.	36	333	476	188	129	154	332	51	261	183	328	151
Salix 4 mm.	150	1751	1984	1317	1509	1108	1894	1414	1085	2310	1109	1259
Salix 4 ff.	150	1418	1755	1038	905	827	1768	1529	821	1443	875	1090
Salix 5 mm.	150	612	844	945	1052	417	831	513	287	972	954	326
Salix 5 ff.	150	371	1314	1333	1365	525	1209	681	526	1082	1170	434
Salix 6 mm.	150	-	2162	2445	591	525	1565	137	447	2264	2016	1365
Salix 6 ff.	150	1145	2736	2010	947	1085	2401	406	1875	3599	1715	1570
Salix 7 mm.	60	494	621	746	287	351	515	274	172	405	918	-
Salix 7 ff.	60	839	512	705	180	266	570	318	207	548	1002	-
Saxifraga 1	7	1213	463	159	36	190	124	23*	293	124	55	270
Saxifraga 2	6	561	584	522	167	311	98	123	171	234	89	484
Saxifraga 3	10	509	609	241	150	394	134	84	506	540	653	436
Silene 1	7	1191	1187	312	430	84	171	159	1085	691	603	980
Silene 2	6	917	1406	740	540	268	267	260	288	489	408	354
Silene 3	10	1000	719	503	739	378	176	168	493	485	406	181
Silene 4	1	794	509	483	312	420	373	499	424	611	435	-
E. scheuz. 1	10	843	780	201	302	533	310	98	194	308	225	124
E. scheuz. 2	6	339	956	597	540	142	193	61	57	19	56	16
E. scheuz. 3	10	237	359	67	44	31	37	17	21	65	116	30
E. scheuz. 4	8	445	342	57	23	55	74	14	153	54	121	145
E. triste 1	10	11	12	0	0	1	1	0	1	0	0	0
E. triste 2	6	39	117	44	49	13	14	25	27	9	2	1
E. triste 3	10	0	0	0	0	0	0	0	0	0	0	0
E. triste 4	8	0	0	0	0	0	0	0	0	0	0	0

Due to technical problems, the 2011 and 2012 NDVI inferred from satellite images have not been presented yet, and therefore the NDVI inferred from a Landsat satellite image from 24 July 2011, 4 August 2012 and 20 July 2013 are presented in Table 4.6. The mean landscape NDVI in the 2011 season was a bit below the average of the previous seasons; while both 2012 and 2013 were lower than average (table 4.7).

4.2 Arthropods

All five pitfall trap stations (with four pitfall traps each) and the one window trap station (four trap chambers) were open during the 2013 season. Sampling procedures were concurrent with previous years. Field work was carried out by Palle Smedegaard Nielsen, Lars Holst Hansen, Jakob Humaidan and Jannik

Table 4.5 Peak NDVI recorded in 16 plant plots 2003-2013 together with date of maximum values as day of year (DOY). NDVI values from 2003-2006 are based on data from hand held Ratio Vegetation Index (RVI) measurements, and have been recalculated to account for varying incoming radiation that otherwise affects the measurements. Note that the greening measured accounts for the entire plant community, in which the taxon denoted may only make up a smaller part. Data from 2004 are not included due to instrumental error that season.

	1999		2000		2001		2002		2003		2005		2006	
Plot	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**
Cassiope 1	0.39	203	0.39	211	0.4	203	0.4	224	0.37	210	0.37	217	0.36	220
Cassiope 2	0.39	210	0.41	204	0.41	203	0.39	210	0.39	217	0.40	217	0.38	220
Cassiope 3	0.34	203	0.35	204	0.37	203	0.34	210	0.34	217	0.38	210	0.35	224
Cassiope 4	0.41	203	0.42	204	0.41	203	0.38	217	0.40	210	0.44	210	0.41	220
Dryas 1	0.47	203	0.42	204	0.44	203	0.43	210	0.43	189	0.39	190	0.37	220
Dryas 2/*Salix* 7	0.46	231	0.47	211	0.47	203	0.51	217	0.47	203	0.48	217	0.46	220
Dryas 3	0.50	203	0.49	204	0.51	203	0.51	210	0.50	203	0.46	196	0.45	220
Dryas 4	0.41	203	0.38	204	0.42	203	0.40	210	0.38	203	0.41	210	0.38	212
Dryas 5	0.36	203	0.34	204	0.37	203	0.36	210	0.34	196	0.33	210	0.30	212
Dryas 6/*Papaver* 4	0.43	238	0.46	204	0.46	203	0.47	217	0.45	203	0.47	210	0.44	220
Eriophorum 1	0.57	210	0.58	196	0.61	203	0.61	210	0.59	189	0.60	196	0.60	220
Eriophorum 2	0.54	210	0.54	204	0.56	203	0.54	210	0.53	203	0.52	196	0.52	220
Eriophorum 3	0.53	231	0.53	204	0.52	203	0.53	210	0.50	203	0.47	196	0.47	220
Eriophorum 4	0.67	217	0.69	204	0.69	203	0.70	217	0.71	189	0.72	210	0.72	220
Papaver 1	0.40	210	0.41	204	0.42	203	0.45	210	0.42	203	0.42	217	0.41	220
Papaver 2/*Salix* 5	0.41	210	0.43	204	0.44	203	0.45	210	0.43	203	0.46	210	0.44	220
Papaver 3	0.41	203	0.42	204	0.43	203	0.42	210	0.42	203	0.45	210	0.41	212
Salix 1	0.57	203	0.54	204	0.56	203	0.56	210	0.57	189	0.52	196	0.51	220
Salix 2	0.52	210	0.52	204	0.54	203	0.55	210	0.53	189	0.52	196	0.53	220
Salix 3	0.45	203	0.44	204	0.46	203	0.46	210	0.43	189	0.41	210	0.41	220
Salix 4	0.51	203	0.49	204	0.51	203	0.52	210	0.50	189	0.49	196	0.49	220
Salix 6	na	na	na	na	na	na	na	na	0.48	212	0.48	210	0.46	220
Saxifraga/*Silene* 1	0.30	203	0.27	204	0.29	203	0.26	210	0.27	196	0.24	210	0.24	212
Saxifraga/*Silene* 2	0.37	203	0.38	204	0.40	203	0.37	210	0.39	189	0.37	190	0.34	212
Saxifraga/*Silene* 3	0.29	203	0.29	204	0.32	182	0.29	210	0.29	203	0.27	210	0.27	212
Silene 4	0.36	203	0.38	196	0.37	203	0.37	217	0.35	196	0.39	210	0.35	224
Mean of all	**0.44**	**208.9**	**0.44**	**203.9**	**0.46**	**202.2**	**0.45**	**212.0**	**0.44**	**199.8**	**0.44**	**205.8**	**0.43**	**218.5**

	2007		2008		2009		2010		2011		2012		2013	
Plot	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**	**NDVI**	**DOY**
Cassiope 1	0.35	218	0.36	239	0.33	238	0.32	224	0.31	189	0.33	204	0.28	180
Cassiope 2	0.37	218	0.39	239	0.36	205	0.39	216	0.37	208	0.41	225	0.33	180
Cassiope 3	0.41	218	0.34	239	0.31	213	0.33	217	0.30	217	0.30	204	0.29	188
Cassiope 4	0.39	218	0.45	239	0.39	238	0.38	211	0.35	217	0.39	204	0.37	195
Dryas 1	0.35	218	0.41	239	0.37	205	0.38	203						
Dryas 2/*Salix* 7	0.49	218	0.49	239	0.48	213	0.47	210						
Dryas 3	0.42	190	0.43	206	0.44	205	0.51	189						
Dryas 4	0.36	211	0.40	239	0.36	205	0.36	183						
Dryas 5	0.26	176	0.35	239	0.31	213	0.33	203						
Dryas 6/*Papaver* 4	0.43	218	0.47	250	0.46	238	0.44	203						
Eriophorum 1	0.51	190	0.57	219	0.54	205	0.55	203	0.49	196	0.55	211	0.44	180
Eriophorum 2	0.47	218	0.51	206	0.49	213	0.51	203	0.52	196	0.54	218	0.46	195
Eriophorum 3	0.43	218	0.50	206	0.53	213	0.51	203	0.47	182	0.48	204	0.37	195
Eriophorum 4	0.68	197	0.64	206	0.67	196	0.69	203	0.63	210	0.72	218	0.62	195
Papaver 1	0.41	218	0.42	239	0.40	213	0.42	203	0.39	189	0.41	218	0.36	180
Papaver 2/*Salix* 5	0.45	218	0.44	239	0.42	213	0.43	217	0.41	217	0.44	225	0.41	202
Papaver 3	0.40	218	0.46	239	0.38	238	0.39	211	0.36	196	0.39	204	0.37	195
Salix 1	0.51	197	0.53	206	0.50	213	0.56	183	0.50	196	0.58	197	0.53	195
Salix 2	0.48	197	0.50	211	0.47	205	0.53	203	0.48	196	0.52	221	0.44	188
Salix 3	0.38	197	0.41	206	0.37	213	0.39	189	0.38	182	0.40	204	0.34	180
Salix 4	0.47	218	0.48	206	0.44	213	0.47	196	0.44	196	0.45	204	0.40	195
Salix 6	0.47	218	0.44	239	0.42	213	0.46	211	0.42	210	0.44	211	0.40	188
Saxifraga/*Silene* 1	0.20	218	0.22	250	0.24	245	0.24	203						
Saxifraga/*Silene* 2	0.35	218	0.37	206	0.37	238	0.29	183						
Saxifraga/*Silene* 3	0.25	218	0.27	239	0.27	231	0.26	175						
Silene 4	0.39	218	0.38	239	0.38	213	0.34	217						
Mean of all	**0.41**	**210.7**	**0.43**	**227.8**	**0.41**	**217.2**	**0.42**	**202.4**						

Table 4.6 Area size (km^2) and Normalised Difference Vegetation Index (NDVI) values for 13 sections of the bird and musk ox monitoring areas in the Zackenberg valley together with the lemming monitoring area based on an Landsat satellite image from 24 July 2011, 4 August 2012 and 20 July 2013 (see Schmidt et al. (2014) for position of the snow sections). The images have been corrected for atmospheric (humidity, aerosols, and solar angle) and terrain effects. All negative NDVI values, i.e. from water and snow-covered areas, have been replaced by zeros.

Section	2011				2012				2013			
	Min.	Max.	Mean	St. dev.	Min.	Max.	Mean	St. dev.	Min.	Max.	Mean	St. dev.
1 (0-50 m)	0.00	0.77	0.32	0.19	0.00	0.82	0.30	0.29	0.00	0.76	0.32	0.18
2 (0-50 m)	0.00	0.76	0.40	0.18	0.00	0.85	0.37	0.32	0.00	0.76	0.33	0.19
3 (50-150 m)	0.05	0.74	0.42	0.12	0.00	0.82	0.39	0.30	0.00	0.76	0.33	0.19
4 (150-300 m)	0.05	0.63	0.34	0.13	0.00	0.76	0.28	0.26	0.00	0.76	0.33	0.19
5 (300-600 m)	0.00	0.58	0.23	0.13	0.00	0.68	0.21	0.21	0.00	0.76	0.32	0.19
6 (50-150 m)	0.00	0.64	0.36	0.15	0.00	0.74	0.34	0.29	0.00	0.76	0.32	0.19
7 (150-300 m)	0.02	0.64	0.37	0.15	0.00	0.73	0.31	0.27	0.00	0.76	0.32	0.19
8 (300-600 m)	0.00	0.71	0.27	0.19	0.00	0.80	0.25	0.27	0.00	0.76	0.31	0.19
9 (0-50 m)	0.00	0.73	0.42	0.14	0.00	0.85	0.39	0.29	0.00	0.76	0.32	0.19
10 (50-150 m)	0.00	0.75	0.47	0.11	0.00	0.78	0.43	0.25	0.00	0.70	0.35	0.19
11 (150-300 m)	0.00	0.68	0.36	0.15	0.00	0.73	0.28	0.26	0.00	0.70	0.34	0.18
12 (300-600 m)	0.00	0.77	0.33	0.18	0.00	0.84	0.28	0.27	0.00	0.76	0.33	0.18
13 (Lemmings)	0.00	0.73	0.36	0.17	0.00	0.84	0.38	0.27	0.00	0.70	0.34	0.18
Total	0.00	0.77	0.37	0.17	0.00	0.85	0.33	0.29	0.00	0.75	0.33	0.19

Table 4.7 Mean NDVI values for 13 sections of the bird and musk ox monitoring areas in the Zackenberg valley together with the lemming monitoring area based on Landsat TM, ETM+ and SPOT 4 HRV and ASTER satellite images 1995-2013 (see Schmidt et al. 2014) for position of sections). The data have been corrected for differences in growth phenology between years to simulate the 31 July value, i.e. the approximate optimum date for the plant communities in most years. Data from 2003 are not available due to technical problems.

Section	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
1 (0-50 m)	0.37	0.43	0.44	0.44	0.30	0.41	0.34	0.34	–	0.42	0.41	0.39	0.37	0.37	0.28	0.35	0.32	0.30	0.32
2 (0-50 m)	0.43	0.5	0.5	0.51	0.41	0.48	0.43	0.44	–	0.50	0.49	0.47	0.44	0.49	0.35	0.44	0.40	0.37	0.33
3 (50-150 m)	0.54	0.53	0.54	0.53	0.41	0.51	0.47	0.49	–	0.54	0.53	0.48	0.46	0.53	0.41	0.51	0.42	0.39	0.33
4 (150-300 m)	0.46	0.45	0.46	0.44	0.31	0.43	0.36	0.38	–	0.41	0.40	0.38	0.35	0.46	0.32	0.40	0.34	0.28	0.33
5 (300-600 m)	0.36	0.35	0.38	0.38	0.22	0.37	0.26	0.26	–	0.31	0.30	0.28	0.24	0.38	0.20	0.27	0.23	0.21	0.32
6 (50-150 m)	0.48	0.48	0.47	0.46	0.33	0.44	0.39	0.41	–	0.46	0.45	0.43	0.40	0.47	0.32	0.43	0.36	0.34	0.32
7 (150-300 m)	0.48	0.46	0.48	0.45	0.32	0.43	0.38	0.39	–	0.45	0.44	0.40	0.37	0.47	0.33	0.43	0.37	0.31	0.32
8 (300-600 m)	0.42	0.38	0.41	0.42	0.25	0.35	0.28	0.29	–	0.33	0.32	0.32	0.28	0.38	0.21	0.31	0.27	0.25	0.31
9 (0-50 m)	0.42	0.5	0.52	0.51	0.39	0.50	0.44	0.45	–	0.52	0.51	0.47	0.44	0.53	0.37	0.47	0.42	0.39	0.32
10 (50-150 m)	0.52	0.53	0.54	0.52	0.40	0.52	0.48	0.48	–	0.55	0.54	0.49	0.46	0.55	0.42	0.49	0.47	0.43	0.35
11 (150-300 m)	0.47	0.45	0.46	0.42	0.26	0.41	0.35	0.36	–	0.45	0.44	0.39	0.38	0.51	0.36	0.41	0.36	0.28	0.34
12 (300-600 m)	0.42	0.42	0.44	0.45	0.28	0.32	0.34	0.33	–	0.41	0.40	0.39	0.33	0.45	0.27	0.38	0.33	0.28	0.33
13 (Lemmings)	0.42	0.49	0.5	0.49	0.40	0.47	0.41	0.43	–	0.48	0.47	0.45	0.42	0.48	0.34	0.45	0.36	0.38	0.34
Total	0.45	0.46	0.48	0.47	0.32	0.43	0.38	0.38	–	0.45	0.44	0.42	0.39	0.47	0.32	0.41	0.37	0.33	0.33

Hansen. Samples were sorted by personnel from Department of Bioscience, Aarhus University, Denmark. The material is stored in 96 % ethanol (before 2008 in 70 % ethanol) at the Museum of Natural History, Aarhus. Please contact the BioBasis manager, Niels Martin Schmidt (nms@dmu.dk) regarding access to the collection. The total number of arthropods collected in 2013 was 22276, which is a very low number.

Ice and snow at the arthropod trap stations melted very early in 2013; with dates of 50 % snow or ice cover being earlier than for all previous years in all plots (table 4.8).

Table 4.8 Day of year (DOY)) of 50 % snow cover in the arthropod stations (ice-cover on pond at station 1) in 2003-2013. a) 0 % snow, b) <1 % snow, c) 7 % ice cover, d) 3 % snow, e) 31 % snow, f) 2 % snow, g) 6 % snow, h) 11 % snow.

Station	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Arthropod 1	163	<153[c]	<140	156	148	154	144	151	141	155	136
Arthropod 2	152	<153[a]	<140[a]	<147	<146[a]	147	135	<142[a]	<136[a]	158	137
Arthropod 3	171	156	154	174	158	172	147	162	156	175	140
Arthropod 4	162	158	156	179	161	174	138	163	153	178	134
Arthropod 5	156	<153[a]	<140	154	<176[b]	150	138	145	<136[e]	154	<129[g]
Arthropod 7	153	<153[a]	<140	<147	<176[b]	144	134	<142[d]	<136[f]	151	<129[h]

Window traps

In 2013, window traps were opened 19 May (day 139). The traps worked continuously until 21 September (day 264). The total number of specimens caught in the window traps, in May, June, July and August 2013, was 6947 (table 4.9). This is the second lowest number caught during the BioBasis programme – only 1998 had a lower number.

The ladybird *Coccinella transversoguttata* was first caught in pitfall traps in 2009 (cf. Hansen et al. 2010), but was not caught this year (table 4.10).

In 2013, a very low number of midges, Chironomids, were caught in the window traps. Nonetheless, 75 % of all window-trapped insects in May, June, July and August were Chironomids. The house fly group, Muscidae, was caught in numbers just below the average for the previous seasons. Ichneumonid wasps, Ichneumonidae, were caught in high numbers. Both wolf spiders, Lycosidae, were caught in high numbers, whereas dwarf spiders, Lyniphiidae, were caught in low numbers. Both groups' numbers vary markedly between years. Mites and ticks, Acarina, were caught in low numbers.

Table 4.11 summarises the 2013 window trap captures in the extended autumn season until day 264 (21 September) with totals for 2009-2012 for comparison.

Pitfall traps

The first pitfall traps were established 12 May (day 132), and all traps were in use from 3 June (day 164) and until 21 September (day 264). During May, June, July and August 2013, the number of trap days was 1486 and the total number of specimens caught was 13375. Weekly totals in this period were pooled for all five stations and are presented in table 4.8 with totals from previous years for comparison.

Collembola, spring tails, were caught in low numbers. Thysanoptera were caught in higher numbers than in previous years, even higher than 2012, the previously highest numbers. Hecla sulphur *Colias hecla* was caught in the second highest numbers. Fritillaries, *Clossiana* sp., were caught in high numbers. No Nematocera larvae were caught. These were caught in high numbers previously, but have not been caught by BioBasis at Zackenberg since 2009. Only one mosquito, Culicidae, was caught in 2013; the lowest number since 2007. Midges, Chironomidae, were caught in new record low numbers; less than 10 % of the 1996-2012 average (3195.3).

Mycetophilidae (belonging to fungus gnats) were caught in very low numbers, and dark-winged fungus gnats, Sciaridae, were caught in very low numbers. Scuttle flies, Phoridae, were caught in low numbers; numbers vary highly between years. House flies, Muscidae, were caught in the lowest numbers ever. The emergence of house flies showed only one low peak (figure 4.2). Ichneumon wasps, Ichneumonidae, were caught in moderate numbers compared with previous years. The Greenland ladybird seemed to have

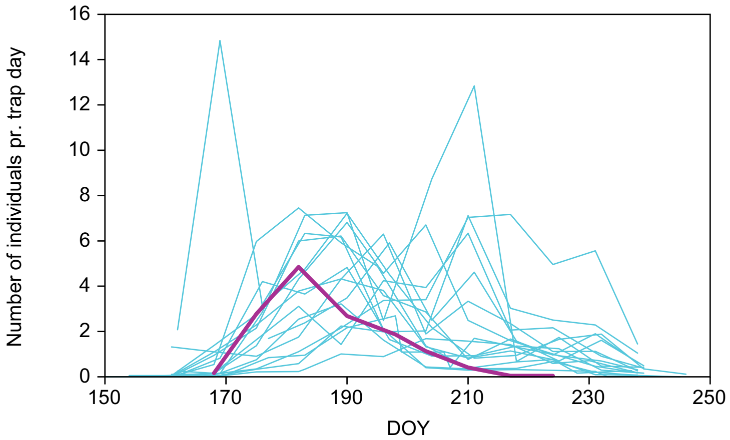


Figure 4.2 Numbers of house flies, Muscidae, caught per trap day every week in the pitfall traps in 2013 (purple line) compared with 1996-2009, 2011 and 2012 (blue lines). Only part of the samples from the 2010 season is available, and 2010 is hence not included in the figure.

Table 4.9 Weekly totals of arthropods etc. caught in the window trap stations during summer 2013. The station holds two window traps situated perpendicular to each other. Each window measures 20×20 cm. Values from each date represents catches from the previous week. Totals from previous years are given for comparison. Asterisks mark groups not separated from related groups that particular year.

DOY/Year	**147**	**153**	**161**	**168**	**175**	**182**	**190**	**196**	**203**	**210**	**217**	**224**	**231**	**238**
No. of trap days	**32**	**24**	**32**	**28**	**28**	**28**	**32**	**24**	**28**	**28**	**28**	**28**	**28**	**28**
COLLEMBOLA						1	1			1	8			
COLEOPTERA														
Latridius minutus														
Latrididae														
Coccinella transversoguttata														
Coccinella transversoguttata, larvae														
HEMIPTERA														
Nysius groenlandicus								1		6	1	1		
Aphidoidea														
Coccoidea												1		
Psylloidea														
PSOCOPTERA														
THYSANOPTERA				4	4	12	1	6	3	6	4	5	2	7
LEPIDOPTERA														
Lepidoptera larvae														
Tortricidae						1	1				1			
Colias hecla					1	2	3	9	6	2				
Clossiana sp.								1		1		1		
Lycaenidae														
Geometridae														
Noctuidae							3		5	1				
DIPTERA														
Nematocera larvae														
Nematocera undet.														
Tipulidae														
Trichoceridae														
Culicidae		1				3	6	7	3	4				
Chironomidae			43	2988	780	1047	264	106	97	59	20	15	4	7
Ceratopogonidae					1	6	28	25	18	6	1	1		
Mycetophiliidae							1	1	2	2		4		
Sciaridae				7	29	54	51	48	15	26	7	1	3	1
Cecidomyiidae														
Empididae					1	21	9	6	2	1				
Cyclorrhapha, larvae														
Phoridae					1	1				2				
Syrphidae		1					1	1	1			1		
Heleomyzidae				1					1		1			
Piophilidae		14		2						2				
Agromyzidae			8									1		
Tachinidae		9		2			3	5	3	3	2	5		
Calliphoridae			4	13			1	1						
Scatophagidae		1	1	1	3	6	2							
Anthomyidae			4	7	1		2	3	5	4	2	3	1	9
Muscidae			2		131	233	202	77	75	5	3	3		1
HYMENOPTERA														
Bombus sp.					2	1	2	1						
Ichneumonidae					2	2	9	18	12	11	2	5	1	1
Braconidae				1										
Chalcidoidea											1	1		
Latridiidae														
Ceraphronoidea						1	1	1				2		
ARANEA														
Lycosidae						1	2	1	8	5		2		3
Linyphiidae				1			1			1		2		
Unidentified *Aranea*											1			
ACARINA				4		16	1	2	6	8		10	2	
NOTOSTRACA														
Lepidurus arcticus														
Total		**26**	**62**	**3031**	**956**	**1408**	**595**	**320**	**262**	**156**	**54**	**64**	**13**	

2013	2012	2011	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996
340	**156**	**194**	**196**	**176**	**184**	**178**	**195**	**172**	**168**	**168**	**168**	**166**	**153**	**174**	**184**	**182**
11	24	13	70	71	33	58	112	175	31	191	119	102	61	5	15	65
0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	3	0	3	1	1	6	10	0	1	0	0	0	0	0	4
0	0	2	0	1	0	0	8	3	1	0	2	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	14
0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0
54	10	12	2	13	5	7	7	11	0	3	1	0	0	0	0	8
0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	1	9	2	6	0	2	0	0	0	1
3	0	3	6	3	9	3	1	5	4	1	1	2	1	1	1	6
0	0	10	1	1	13	3	0	0	0	0	0	0	0	0	0	0
0	0	1	0	0	0	0	0	0	0	2	3	0	0	0	1	3
9	0	5	8	6	1	4	7	1	1	0	0	0	0	0	2	2
0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	1418	0	0	0	0	0
0	0	2	0	0	0	0	0	0	1	0	0	0	1	0	0	0
0	0	1	0	0	0	0	0	2	0	0	0	0	0	1	1	0
23	133	63	71	88	53	68	128	104	96	232	209	111	322	138	142	98
5430	17993	7344	9402	14207	12788	9290	6470	5203	7792	6378	3876	8522	5787	3743	7725	6477
86	16	26	60	17	83	32	9	21	66	1598	168	*	1799	*	*	*
10	31	42	36	21	7	17	18	21	2	6	23	11	16	624	240	64
242	90	121	67	613	179	125	749	53	12	56	33	13	171	*	*	*
0	1	1	0	1	0	0	0	0	0	3	4	32	6	0	0	1
40	2	16	3	1	8	9	7	7	8	1	8	10	9	9	1	77
0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
4	1	2	0	0	1	3	0	0	0	1	1	2	3	0	0	0
4	1	8	5	11	9	8	10	12	6	10	4	5	1	8	16	4
3	0	3	1	0	0	0	0	0	0	1	2	0	1	0	0	0
4	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
9	3	5	0	1	3	17	99	34	2	3	0	0	0	0	4	0
23	1	4	9	2	1	3	7	10	7	0	2	6	1	0	0	0
19	0	4	12	3	5	1	9	4	1	1	1	4	5	7	6	2
13	42	15	81	6	15	0	31	11	3	7	0	2	10	0	30	11
41	602	87	83	88	65	43	28	12	10	8	2	*	3	26	11	*
732	579	1350	374	522	514	394	935	1423	866	554	1312	1455	754	745	809	1355
6	1	3	0	2	3	0	7	5	3	1	0	0	1	2	6	5
63	15	95	78	29	29	33	68	47	70	24	34	48	24	18	44	43
1	0	0	0	1	1	0	0	1	0	0	0	0	0	1	1	0
2	0	0	0	3	3	1	1	1	1	2	14	0	0	0	2	0
0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
5	1	0	3	1	0	0	0	0	2	0	0	0	0	0	0	0
22	51	6	6	17	18	31	10	1	1	1	0	2	0	0	1	0
5	66	24	3	15	2	8	12	4	8	8	15	10	6	1	1	8
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
49	59	16	25	7	27	120	704	524	54	347	358	246	191	826	189	299
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6947	**19745**	**9288**	**10412**	**15755**	**13876**	**10279**	**9444**	**7717**	**9050**	**9448**	**7610**	**10588**	**9177**	**6155**	**9248**	**8547**

Table 4.10 Weekly totals of arthropods etc. caught at the five pitfall trap stations during summer 2013. Each station holds eight yellow pitfall traps measuring 10 cm in diameter. Values from each date represent catches from the previous period. Totals from previous years are given for comparison. Asterisks mark groups that were not separated from closely related groups in that year.

DOY/Year	**140**	**147**	**154**	**161**	**168**	**175**	**182**	**190**	**198**	**203**	**210**	**217**	**224**	**231**	**238**
No. of active stations	1	4	5	5	5	5	5	5	5	5	5	5	5	5	5
No. of trap days	64	115	131	140	147	140	140	160	120	140	140	140	140	140	140
COLLEMBOLA		31	67	68	128	75	306	270	88	20	12	7	293	52	69
HEMIPTERA															
Nysius groenlandicus					2		1	8	8	4	5	5	1	2	10
Aphidoidea							1	2	3	5	3	7	11	20	19
Coccoidea			3	1	2		4	6	37	21	45	85	29	20	3
THYSANOPTERA			2	19	6	3	2	6	10	6	24	11	4	2	2
LEPIDOPTERA															
Lepidoptera larvae				2	17	6	8	28	30	25	16	6	3	1	2
Tortricidae						3		1							
Colias hecla							2	35	23	42	23	5			
Clossiana sp.						4	3	22	43	91	78	22	4		
Lycaenidae												1			
Plebeius franklinii															
Geometridae															
Noctuidae						1	3	1		9	11			1	
Unidentified *Lepidoptera*															
DIPTERA															
Unidentified *Diptera* larvae															
Nematocera larvae															
Tipulidae larvae															
Tipulidae								2	1						
Trichoceridae															
Culicidae								1							
Chironomidae					23	29	59	134	34	13	1				
Ceratopogonidae							1	1							
Mycetophiliidae								2	3						
Sciaridae				1	183	246	118	134	69	46	16	3		5	
Cecidomyiidae					2				32						
Brachycera larvae															
Empididae							1	1							
Cyclorrhapha larvae													1	1	
Phoridae							1			65	94	94	944	104	36
Syrphidae						1	1	2		2	3	1	1		
Heleomyzidae															
Agromyzidae	7	14	6	6							1		1	6	8
Tachinidae						1	9	11	5	8	20	7	5	5	4
Calliphoridae	1	2	47	41								1		1	
Scatophagidae															1
Fannidae															
Anthomyiidae		1	9	76	1	3	1	1			1		11	5	10
Muscidae					24	389	679	430	224	159	58	7	7		
SIPHONAPTERA															
HYMENOPTERA															
Tenthredinidae															
Hymenoptera larvae								1	3	2					
Bombus sp.				1	5		2	4	2			1	1		
Ichneumonidae				2	6	9	11	32	45	52	44	41	27	10	20
Braconidae					1	3		5		3		4	1		5
Chalcidoidea				1	3		5	9	11	28	59	19	40	18	9
Scelionidae															
Ceraphronoidea							1	2		1	2		1		
Cynipoidae															
COLEOPTERA															
Coccinella transversoguttata															
ARANEA															
Thomisidae	1	5	18	31	20	6	9	10	11	22	9	13	2	8	6
Lycosidae	2	18	43	99	250	166	120	97	146	144	650	198	66	37	52
Lycosidae egg sac						6	8	1		1	1	3	2		2
Dictynidae		5	26	3	1		1			1				1	1
Linyphiidae		23	82	124	71	91	50	41	36	51	45	47	31	72	74
Unidentified *Aranea*															
ACARINA		17	37	95	211	136	180	190	162	201	233	246	302	151	148
Total	**11**	**116**	**340**	**570**	**956**	**1178**	**1587**	**1490**	**1026**	**1022**	**1454**	**834**	**1788**	**522**	**481**

2013	2012	2011	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996
70	56	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
1997	1422	1785	1936	1578	1709	2979	3686	3437	3101	3059	2954	3155	2706	2702	2797	(1512)
1486	2747	3193	3781	1633	1292	7100	9586	13277	17510	20312	17970	21726	23443	8957	10830	4636
46	36	11	5	10	4	13	471	96	3	0	2	0	1	0	5	40
71	11	22	12	48	33	61	524	277	1624	157	359	3	11	185	10	6
256	296	231	152	1228	431	617	1092	1288	42	634	9	781	431	3	548	254
97	67	28	27	22	6	2	19	4	0	5	0	0	2	0	0	2
144	17	51	33	43	32	116	82	280	37	63	16	18	21	106	168	354
4	5	1	0	0	0	1	0	0	1	0	1	0	0	0	0	0
130	45	0	0	0	0	0	15	38	156	29	0	77	42	12	19	88
267	37	77	93	178	140	210	174	240	468	381	49	329	82	56	180	1052
1	0	37	15	14	16	45	0	0	0	0	0	4	1	0	0	0
0	0	0	0	0	0	0	1	1	0	7	19	0	0	1	1	2
0	1	0	0	0	0	0	2	2	0	6	0	0	0	0	0	0
26	30	5	13	38	19	19	183	14	110	1	15	4	6	2	45	68
0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	3	2	0	21	10	18	29	46	15	279	105	58	39	52
0	0	2	0	3	1	2	1	6	3	3	3	4	1	0	0	0
3	3	2	2	5	3	4	5	1	7	4	14	2	4	1	4	14
0	0	0	0	0	0	1	0	1	1	1	7	0	3	0	1	0
1	22	19	6	5	0	33	13	19	23	86	34	61	83	22	16	2
293	1209	1225	1316	2415	3559	4365	1492	1596	4768	5982	1958	3666	8542	2402	3337	3292
2	4	11	76	7	97	92	6	16	107	102	7	0	68	*	*	*
5	40	13	30	104	1	74	104	63	70	48	181	37	205	1764	1194	526
821	325	1060	426	548	533	1256	819	912	1101	762	573	787	796	*	*	*
34	2	0	0	1	0	2	8	13	8	6	8	24	0	1	0	0
0	0	0	0	0	0	0	0	0	3	0	0	4	3	0	0	0
2	1	2	7	0	2	2	3	5	8	24	28	14	21	10	6	8
2	4	0	39	3	1	1	77	60	23	22	0	7	7	19	75	16
1338	1403	2964	1610	775	620	461	386	461	665	489	445	1316	435	344	214	118
11	29	6	37	35	28	9	93	45	35	30	18	43	50	28	81	72
0	0	0	0	0	0	1	0	1	1	5	6	1	7	0	0	0
49	19	20	4	11	3	29	151	60	10	6	4	2	0	0	1	0
75	38	49	64	27	19	16	39	42	60	23	29	37	37	0	19	0
93	2	65	237	6	20	6	96	31	17	44	5	218	26	49	48	48
1	1	6	41	18	22	1	106	7	42	24	0	1	41	0	385	26
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
119	184	200	299	213	210	183	535	124	108	238	57	*	88	416	573	*
1977	3231	3897	2919	1647	1525	2313	5464	5623	8385	7499	6766	12805	10005	5463	6217	8114
0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
0	0	0	0	0	0	0	1									
6	2	0	0	0	0	0	3	4	8	0	0	4	0	2	0	0
16	24	11	9	8	14	6	18	40	15	7	3	10	2	6	12	2
299	198	406	250	98	115	269	717	720	974	436	442	710	386	297	567	954
22	32	16	36	35	20	42	80	61	52	11	11	15	10	105	59	44
202	105	175	345	625	437	287	747	746	120	190	106	21	9	2	123	48
0	1	0	0	0	0	4	0	0	310	5	3	0	101	0	0	0
7	15	5	7	9	5	8	17	13	3	8	3	15	5	0	0	0
0	1	0	0	1	0	0	24	3	0	0	1	0	0	0	1	0
0	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
171	116	130	93	101	121	164	98	90	164	219	177	134	144	89	245	198
2088	1531	2523	1040	2162	2450	2869	3316	3428	3438	1760	2618	3254	2118	2123	3806	4548
24	18	27	23	91	18	56	45	69	85	12	85	101	160	160	138	82
39	6	18	11	12	11	10	84	40	18	107	0	0	79	0	53	0
838	837	445	360	229	261	834	1411	1483	2526	1438	1833	3523	2243	1108	1644	1436
0	3															
2309	3203	3899	1748	2835	1141	3837	10096	17616	18602	21282	9929	15256	8263	6304	19781	8182
13375	**17388**	**20852**	**15171**	**15247**	**13210**	**25916**	**38217**	**48935**	**61756**	**62523**	**43811**	**65344**	**58174**	**30095**	**50446**	**34404**

Table 4.11 Weekly totals of arthropods etc. caught at the five pitfall stations and the window trap station during autumn 2013. Values from each date represent catches from the previous period. Totals from previous years are given for comparison.

	Window traps									Pitfall traps								
DOY/Year	**244**	**245**	**252**	**264**	**2013**	**2012**	**2011**	**2010**	**2009**	**245**	**252**	**259**	**264**	**2013**	**2012**	**2011**	**2010**	**2009**
No. of active stations	1	1	1	1	1	1	1	1	1	5	5	5	5	20	25	5	5	5
No. of trap days	24	4	28	48	104	68	56	48	56	140	140	140	100	520	696	720	700	600
COLLEMBOLA					0	3	0	35	2	111	882	67	3	1063	229	190	416	56
HEMIPTERA																		
Nysius groenlandicus					0	0	0	0	0	3	31	3		37	28	51	1	3
Aphidoidea					0	0	0	0	0	18	14	2		34	4	15	8	0
Coccoidea					0	0	0	1	0					0	1	0	2	0
THYSANOPTERA		1	5		6	0	6	0	0				2	2	2	1	1	1
LEPIDOPTERA																		
Lepidoptera larvae					0	0	0	0	0					0	5	1	0	2
Clossiana sp.					0	0	0	0	0					0	0	0	0	2
DIPTERA																		
Culicidae					0	0	0	0	0				1					
Chironomidae	13	7	5	1	26	8	147	20	6	2	8	1	2	13	2	7	1	7
Ceratopogonidae					0	0	0	1	0					0	0	0	0	0
Mycetophiliidae					0	4	1	0	2	7				7	2	3	4	5
Sciaridae					0	0	0	0	0		3			3	1	1	1	2
Syrphidae					0	0	0	1	0		1			1	1	0	1	2
Cyclorrhapha larvae					0	0	0	0	0		1			1	6	0	0	0
Phoridae					0	0	0	21	0		1			1	124	18	316	0
Agromyzidae			2		2	2	2	1	0	16	4	7	5	32	10	10	9	2
Tachinidae					0	0	0	0	0					0	0	1	1	0
Calliphoridae			1		1	0	1	0	3	1	2			3	0	1	0	12
Scatophagidae					0	0	10	16	4					0	1	5	7	12
Anthomyiidae	3	4	4		11	10	22	13	6	5	17	1		23	25	47	10	31
Muscidae					0	7	9	5	0					0	11	6	9	2
HYMENOPTERA																		
Ichneumonidae	1		1		2	1	3	4	1	7	16	1	1	25	42	36	61	9
Braconidae					0	0	0	0	0	6	13	6		25	4	2	0	5
Chalcidoidea					0	0	0	18	0		1			1	12	6	12	11
Ceraphronoidea					0	1	0	0	0	2	1			3	6	1	1	0
COLEOPTERA																		
Coccinella transversoguttata					0	1	0	0	0					0	0	0	0	0
ARANEA																		
Thomisidae					0	0	0	0	0		4	7	1	12	11	11	11	11
Lycosidae	1				1	4	0	19	1	10	16	15	12	53	99	89	30	30
Lycosidae egg sac					0	0	0	0	0					0	1	4	1	5
Dictynidae					0	0	0	2	1			1	3	4	8	13	3	3
Linyphiidae	1		2		3	5	2	17	2	58	87	81	18	244	462	176	212	48
Unidentified *Aranea*					0	0	0	0	0					0	1	0	0	0
ACARINA		**1**			**1**	**3**	**0**	**31**	**2**	**87**	**113**	**91**	**22**	**313**	**30**	**228**	**303**	**34**
Total	**19**	**13**	**20**	**1**	**53**	**49**	**195**	**205**	**30**	**333**	**1215**	**283**	**70**	**1901**	**1128**	**923**	**1421**	**295**

become more numerous in recent years, but none were caught this season (see also under Window traps).

Lycosidae, wolf spiders, were caught in average numbers. Mites and ticks, Acarina, were caught in low numbers.

Table 4.11 summarises the 2013 pitfall trap captures in the extended autumn season until 26 August (day 238) with totals from 2009 to 2012 for comparison.

Insect predation on *Dryas* flowers

Predation on *Dryas* flowers by *Sympistis nigrita* ssp. *zetterstedtii* was recorded in all six plots. The peak percentages of flowers marked by predation were about average for three plots and above average for three plots when compared to previous years (table 4.12).

Table 4.12 Peak ratio (percent) of mountain avens Dryas integrifolia/octopetala *flowers depredated by larvae of* Sympistis nigrita *ssp. zetterstedtii in mountain avens plots in 1996-2013.*

Plots	*Dryas* 1	*Dryas* 2	*Dryas* 3	*Dryas* 4	*Dryas* 5	*Dryas* 6
1996	2	0	11	17	2	0
1997	6	5	18	1	8	0
1998	3	0	3	7	2	0
1999	0	0	0	0	0	0
2000	0	0	0	0	0	0
2001	0	0	0	0	0	0
2002	15	1	7	11	9	0
2003	2	0	1	5	2	0
2004	15	4	33	39	3	1
2005	1	1	10	3	0	0
2006	27	3	6	18	2	6
2007	0	2	8	4	0	5
2008	34	25	67	32	2	8
2009	8	5	27	14	33	5
2010	7	7	16	11	6	47
2011	3	3	6	2	2	4
2012	7	1	12	1	0	0
2013	8	4	42	29	10	5

4.3 Birds

Bird observations were carried out by Palle Smedegaard Nielsen, Jannik Hansen, Lars Holst Hansen and Jakob Humaidan. Other researchers and staff – not least Jeroen Reneerkens and colleagues – provided much valued information throughout the season. Local site names can be found in Schmidt et al. 2014.

Breeding populations

During seven days – between 12 June (day 163) and 22 June (day 173) – a complete, initial census was carried out. An early start of snowmelt meant that the census was easily conducted this season. The completion of the survey took 41 'man-hours', which is near average. The entire census was carried out in good weather conditions. In addition, large parts of the census area were covered regularly during June, July and most of August, exceptions being the closed goose moulting area along the coast and the slopes of Aucellabjerg above 350 m a.s.l. The latter were covered on eight occasions only, in addition to the many visits by Jeroen Reneerkens and colleagues. The total effort in June and July 2013 was near average (139 hours in June and 98 hours in July) compared to previous years. The

Table 4.13 Estimated numbers of pairs/territories in four sectors of the 15.8 km² census area in the Zackenberg valley 2013.

Species	<50 m a.s.l. 7.77 km²	50-150 m a.s.l. 3.33 km²	150-300 m a.s.l. 2.51 km²	300-600 m a.s.l. 2.24 km²	Total
Red-throated diver	4	0	0	0	4
King eider	2	0	0	0	2
Long-tailed duck	4-5	0	0	0	4-5
Rock ptarmigan	0	0	0	0	0
Common ringed plover	8-9	3	6	12	29-30
Red knot	8-10	6	10-12	2	26-30
Sanderling	24-25	3	6	17	50-51
Dunlin	52-64	10	2-3	3	67-80
Ruddy turnstone	5-9	15-16	0	0	20-25
Red-necked phalarope	1-2	0	0	0	1-2
Long-tailed skua	9-11	3-4	0-1	0	12-16
Glaucous gull	0-1	0	0	0	0-1
Arctic redpoll	1-2	1	1	0	3-4
Snow bunting	37	25-26	12	5	79-80

results of the initial census supplemented with records from the rest of the season (see Schmidt et al. 2014) are presented in table 4.13, and compared with the estimates of previous years in table 4.14.

The first red-throated diver *Gavia stellata* was seen 4 June (day 155); while the first settled pairs were recorded the following day, in the fens near the research station. At least three pairs attempted to breed within the census area and two nests were found. Both nests fell victim to predation.

The number of common ringed plover *Charadrius hiaticula* territories was near average. Both red knot *Calidris canutus* and sanderling *Calidris alba* territories were recorded in numbers near average (table 4.14). Dunlin *Calidris alpina* territories were found in numbers just above average. Notice that the dunlin territory numbers in early years are likely to have been underestimated (Meltofte 2006). Ruddy turnstone *Arenaria interpres* territories were found in low numbers (tables 4.13 and 4.14).

No phalarope nests (red-necked phalarope *Phalaropus lobatus* and red phalarope *P. fulicarius*) were found in 2013. On 13 July (day 194), a foraging pair of red-necked phalaropes were recorded on Lomsø, and three days later – nearby – a male was seen with a fledgling. It is unclear whether the male was the same as the one seen in the pair just days before; but they could be different birds.

Long-tailed skua *Stercorarius longicaudus* territories were found in numbers a little below average (table 4.14). Twelve pairs nested in the census area (see below), one pair re-nested after losing the first nest to predation.

Table 4.14 Estimated numbers of pairs/territories in the 15.8 km^2 census area in the Zackenberg valley 2013 compared with the 1996-2012 averages.

Species	No. of territories	Average min. and max no. territories 1996-2012	No. of nests found[1]	Comments
Regular breeders				
Red-throated diver	4	2.4-2.9	2	
Common eider	0	0.3-0.4	0	
King eider	2	1.1-1.9	2	
Long-tailed duck	4-5	5.3-6.3	2	
Rock ptarmigan	0	2.4-3.2	0	
Common ringed plover	29-30	27.8-33.3	3	
Red knot	26-30	24.9-31.4	2	
Sanderling	50-51	51.9-59.3	16	
Dunlin	67-81	76.9-86.5	11	
Ruddy turnstone	20-25	39.8-44.8	6	
Red-necked phalarope	1-2	0.8-1.5	0	
Long-tailed skua	12-16	17.8-21.8	13	One of these. a relay
Glaucous gull	0-1	0.6	0	
Common raven	2	–	0	Nests outside the census area
Snow bunting	79-80	44.3-50.1	0	Nests of passerines are only found opportunistically
Irregular breeders				
Species	**No. of territories**	**Average min. and max. no. territories 1996-2011**	**No. of nests found[1]**	**Comments**
Pink-footed goose	0	0.12	0	Min. 3921 immatures migrated northwards over the area
Eurasian golden plover	0	0.06	0	
Red phalarope	0	0.53-0.76	0	
Snowy owl	0	0.06	0	
Northern wheatear	1	0.00-0.06	0	Nests of passerines are only found opportunistically
Arctic redpoll	3-4	0.6-1.2	0	Nests of passerines are only found opportunistically
Lapland longspur	0	0.12-0.18	0	Nests of passerines are only found opportunistically See Table 4.25

[1]Within the census area

Table 4.15 Median first egg dates for waders at Zackenberg 2013 as estimated from incomplete clutches, egg floating and hatching dates, as well as weights and observed sizes of pulli.

Species	Median date	Range	N	Average 1996-2012
Common ringed plover	158	152-190	3	166.5
Red knot	171	170-172	3	166.7
Sanderling	167	158-184	24	168.6
Dunlin	166	155-176	11	167.2
Ruddy turnstone	160.5	153-167	6	164.3

A glaucous gull *Larus hyperboreus* pair has had a nest on an islet in the same stretch of the river Zackenberg since at least 2004, and they nested here again in 2013. No chicks were seen. Glaucous gulls were seen daily throughout the season. Larger flocks were seen as early as 15 June (day 166; 19 individuals inclusive minimum one immature bird), 6 July (day 187; 13 individuals), culminating with the season's largest flock of 32 individuals 13 July (day 194). During August and September, flocks of 10 and 12 birds were recorded on several occasions. From early September fully fledged juveniles and immatures were observed on numerous occasions. The last glaucous gulls recorded in 2013, were two birds near the research station 29 September (day 272).

No rock ptarmigan *Lagopus muta* territory were recorded in 2012.

The number of snow bunting *Plectrophenax nivalis* territories was the highest since 2005 (table 4.14). In mid to late May, flocks of op to 60 snow buntings were recorded. The first female was recorded as early as 24 May (day 144).

Three to four arctic redpoll *Carduelis hornemanni* territories were recorded this year (table 4.14).

In 2013, only a single male Lapland bunting *Calcarius lapponicus* was seen 29 May singing from the research station radio mast.

Reproductive phenology in waders, Charadriiformes

28.9 % of all wader nests were initiated before 10 June (day 161) and 68.9 % before 20 June (day 171, table 4.15).

The snow cover 10 June (day 161) was 0.2 % and nest initiation was early for common ringed plover. Red knot nest initiation was late, but with only three nests found it might be less representative. The nest initiation was average to near average for the other species (table 4.16).

Reproductive success in waders, Charadriiformes

The all wader nest success was low in 2013 – although higher than in the previous six years. Using the modified Mayfield method (Johnson 1979), 19.7 % of the wader nests were successful.

For the first time during the BioBasis programme, dunlin nests suffered harder than sanderling nests. Ruddy turnstones had a very high success rate, but nested in low numbers (table 4.17). Two red knot nests were found in the census area in 2013, one of which suffering predation. A nest found in adjacent areas, also fell victim to predation.

Table 4.16 Snow cover 10 June together with median first egg dates for waders at Zackenberg 1995-2013. Data based on less than 10 nests/broods are marked with asterisk, less than five are omitted. The snow cover is pooled (weighted means) from section 1, 2, 3 and 4, where the vast majority of the egg laying phenology data originates.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Snow cover on 10 June	84	82	76	80	91	53	84	79	83	48	28	85	48	71	4	72	78	83	0.2
Sanderling		168*	169	169	174.5	168	173.5	168	164	160	166*	181	166	169	167	163	166	175	167
Dunlin	169*	163.5	164	167.5	173	163.5	176	159	163	164	163	178	166	169	162	165.5	173	174	166
Ruddy turnstone	163*	170.5	164	163.5	175	163	174	160	159	160	162	172*	158	170	154	165	162	161	160.5

Table 4.17 Mean nest success (%) 1996-2013 according to the modified Mayfield method (Johnson 1979). Poor data (below 125 nest days or five predations) are marked with asterisk. Data from species with below 50 nest days have been omitted. If no nest was found, it is indicated by "–". Nests with at least one pipped egg or one hatched young are considered successful. Also given are total numbers of adult foxes observed by the bird observer in the bird census area during June and July (away from the research station proper), along with the number of fox dens holding pups.

Species	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
Common ringed plover				60*		38*				–
Red knot	–	–			–		–			–
Sanderling	72*	33–100*	88*	40	46*	19	33*	45	71–85	
Dunlin			28–47	65	68	75*		63	93	43*
Ruddy turnstone	21–68	67–100	16	23–28	29	60*	52	21–27	83	
Red-necked phalarope	–	–	–		–	–	–	–	–	
Red phalarope	–	–	–	–	–	–	–	–	–	–
All waders	**33–63**	**52–100**	**32–37**	**42–44**	**44**	**43**	**43**	**42–44**	**87–90**	**22**
N nests	17	31	44	44	47	32	21	51	55	15
N nest days	163	228	334	520.8	375	328.4	178.9	552	700	104
Fox encounters	14	5	7	13	11	14	21	11	16	18
Fox dens with pups	2	0	1	0	2	2	0–1	2	3	0

Species	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**1996–2013**
Common ringed plover	0*	–	2*	–		–			37.6–40
Red knot	–	100*				3*		8.6	12.1
Sanderling	7*	3	5	7.5	3	17	14.3	29.5	16.3–17.2
Dunlin	47	48	17	80*	62*	21.1*	33.7	18.6*	49.6–52.6
Ruddy turnstone		36	22*	27*	34*	2.9*	9.9*	44.5*	28.8–32.4
Red-necked phalarope	–	–	–		–	–	–	–	
Red phalarope		–	–	–		–	–	–	
All waders	**37**	**18**	**16**	**14**	**9**	**14.4**	**15.3**	**19.7**	**27.3–29.2**
N nests	28	60	58	66	46	47	56	47	730
N nest days	332.2	532.7	423.5	508.5	306.5	349	552.2	483.6	6972.5
Fox encounters	22	23	20	11	9	20	34	13	
Fox dens with pups	2	3	5	3	3	3	5	3	

The number of fox encounters was below average, while numbers of active fox dens was near average (table 4.17). The number of lemming winter nests was 101 (table 4.23).

The mean wader clutch size was 3.8 in 2013; which is near the weighted mean for previous years (table 4.18). Nests containing other than four eggs were: Common ringed plover; all three nests held three eggs – sanderling; two nests of three eggs and one with only two eggs.

In late July and early August, alarming parents – and later juveniles – were found in the fens and marshes (dunlins and sanderlings), and on the slopes of Aucellabjerg and in the dry lowlands (common ringed plovers, red knots, sanderlings, dunlins and turnstones).

Data on chick survival is almost negligible, but survival is considered low. This is partly due to the fact that from 19 July (day 200) to late July, flocks of long-tailed skua roamed the lower slopes of Aucellabjerg and the lowlands' fens and heaths. The largest flocks held nineteen individuals.

Reproductive phenology and success in long-tailed skuas *Stercorarius longicaudus*

All long-tailed skua nests were found to have been initiated before the census period. Only one nest was later; a relay. The mean first egg date was earlier than average (table 4.19). Six collared lemming *Dicrostonyx groenlandicus* were observed by the bird observer, reflecting a season with relatively low numbers of lemming winter nests found (table 4.23). Roaming flocks of long-tailed skuas were seen in the second half of July.

Five observations of a third calendar year bird are all considered to be the same individual. All observations were between 1 and 16 July (day 183 and 198).

Table 4.18 Mean clutch sizes in waders at Zackenberg 1995-2013 compared to the weighted mean of all years (W. mean). Samples of fewer than five clutches are marked with asterisk.

Species	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Common ringed plover	4.00*	4.00*	3.50*	4.00*	3.50*	4.00*	3.50*	4.00*	4.00*	4.00*
Red knot				4.00*	4.00*		4.00*		4.00*	4.00*
Sanderling	4.00*	4.00	3.86	4.00	3.67	4.00	3.43	3.83	4.00	4.00
Dunlin		4.00*	3.75*	3.90	3.70	3.93	3.63	4.00*	4.00	3.92
Ruddy turnstone		3.71	3.79	3.82	3.58	3.80	3.75	4.00	3.77	3.92
Weighted mean	4.00	4.00	3.76	3.90	3.65	3.89	3.63	3.95	3.94	3.94

Species	2005	2006	2007	2008	2009	2010	2011	2012	2013	W. mean
Common ringed plover		3.75*		3.75*		4.00*		3.75*	3.00*	3.71
Red knot			4.00*	4.00*	4.00*	4.00*	4.00*	4.00*	4.00*	3.59
Sanderling	3.75	3.63	3.73	3.77	3.91	3.92	3.85	3.93	3.75	3.84
Dunlin	4.00	3.13	3.79	3.67	4.00	4.00	3.70	3.75	4.00	3.81
Ruddy turnstone	3.86	3.00*	4.00*	3.71	3.78	3.92	3.90	4.00	4.00	3.82
Weighted mean	3.89	3.33	3.76	3.74	3.91	3.80	3.84	3.90	3.81	3.82

Table 4.19 Egg-laying phenology, breeding effort and success in long-tailed skuas Stercorarius longicaudus *at Zackenberg 1996-2013. Median egg laying date is the date when half the supposed first clutches were laid. Number of clutches found includes replacement clutches. Mean hatching success according to the modified Mayfield method (Johnson 1979). Poor data (below 125 nest days or five predations) are marked with asterisk. Nests with at least one pipped egg or one hatched young are considered successful. Please note, that for three nests (outside the census area and in Zone 1c) incubation fate was unknown, hence for the calculation of hatching success n = 12.*

Long-tailed skua breeding	1996	1997	1998	1999	2000	2001	2002	2003	2004
Median 1st egg date		158	163	168	170	166	160	166	160
No. of clutches found	8	17	23	8	5	21	14	7	21
No. of young hatched	1	25	16	2	2	18	14	5	36
Nest success % (Mayfield)		80.6*	26.7	18.1*	17.5*	39.5	44.1	76.2*	94*
Estimated no. of young fledged	0	5	6	1	0	5	4	2	22

Long-tailed skua breeding	2005	2006	2007	2008	2009	2010	2011	2012	2013
Median 1st egg date	159	170	163	164	168	172	165	161	159
No. of clutches found	8	2	15	9	2	1	6	14	6
No. of young hatched	6	1	11	3	1	0	0	3	0
Nest success % (Mayfield)	51.8*	100*	23	33	25.9	0	44	80	0*
Estimated no. of young fledged	1	0	1	2	1	0	0	1	0

Barnacle geese *Branta leucopsis*

During an early June visit to the ice covered bay below the barnacle goose colony on the southern face of the mountain Zackenberg, no individuals were seen in the colony. However, adults flying to and from the cliffs during the breeding season suggest that the colony was in use to some degree. For further details on the colony, see Hansen et al. (2009).

The first barnacle goslings in the Zackenberg valley were seen 9 July (day 190). Eleven broods were seen this season, which is average for the period 2000-2012 (table 4.20). A maximum number of 18 goslings were seen at any one time.

Southward migrating barnacle geese were seen from 11 August (day 223), when 144 flew south. 300 barnacle geese were seen migrating southwards in 2013. The last barnacle geese were a flock of 10 seen flying 6 September (day 249).

The percentage of young in wintering flocks on Isle of Islay, Western Scotland, was not available at the deadline for this report (table 4.20). Immature barnacle geese moulted in numbers above average at Zackenberg (1995-2012 average: 196; table 4.21).

Common birds, not breeding in the census area

Migration of immature pinkfooted geese *Anser brachyrhynchus* was recorded during the summer, showing a curious three peaked pattern. First, four immatures

Table 4.20 Average brood sizes of barnacle geese Branta leucopsis *in the Zackenberg valley during July and early August 1995-2013, together with the total number of broods brought to the valley. Samples of fewer than ten broods are marked with asterisk. Average brood size data from autumn on the Isle of Islay in Scotland are given for comparison, including the percentage of juveniles in the population (M. Ogilvie pers. comm.).*

Decade	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Primo July		3.0*	3.1	2.9*	1.9	3.2*	1.8*	2.4	1.8*	2.6
Medio July		2.3*	2.7	2.3	1.8	3.1*	1.7*	2.4	1.2*	2.3
Ultimo July	2.0*	3.0*	2.6	2.2	1.7	3.1		2.3	1.1*	2.3
Primo August	2.3*	2.3*	2.4		1.8		2.0*	2.2	1.2*	1.9*
No. of broods	≥7	6-7	19-21	≥18	29	11	4	32	8	26
Scotland	2.00	2.30	1.95	2.28	1.92	2.20	1.94	2.23	1.59	2.35
Percent juv.	7.2	10.3	6.1	10.5	8.1	10.8	7.1	12.5	6.4	15.9

Decade	2005	2006	2007	2008	2009	2010	2011	2012	2013
Primo July	1.7*	2.0*	1.3	4*	1*	1.5*	0	0	1.0*
Medio July	2.7	1.5*	1.5	1.6	1.33*	1.8*	1*	1.5	1.6
Ultimo July	2.2*	1.1*	3.3*	1.5*	1*	1.4*	0	1.1	1.7*
Primo August		1.5*	-	1*	1.5*	1.6*	0	1.3	1.3*
No. of broods	14	9	28	15	9	18	3	11	11
Scotland	1.67	1.15	2.14	1.9	1.9	2.26	2.1	1.8	N/A
Percent juv.	6.3	3.23	9.8	8.2	3.8	11.2	11.2	7.0	N/A

Table 4.21 Number of immature pink-footed geese Anser brachyrhynchus *and barnacle geese* Branta leucopsis *moulting in the study area at Zackenberg 1995-2013.The closed area is Zone 1c (see www.zackenberg.dk/maps).*

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Pink-footed goose										
Closed moulting area and further east	310	246	247	5	127	35	0	30	41	11
Coast west of closed area	230	40	60?	0	29	0	0	0	0	10
Upper Zackenberg valley	0	0	15	0	0	0	0	0	0	0
Pink-footed goose total	540	286	322	5	156	35	0	30	41	21
Barnacle goose										
Closed area at Lomsø and Kystkærene	21	0	29	21	60	84	137	86	120	81
Coast east of closed area	>120	150?	96	55	66	0	109	80	45	0
Coast west of closed area	0	0	0	0	0	30	0	0	0	0
Upper Zackenberg valley	41	85	2	75	<57	27	60	0	14	0
Barnacle goose total	>182	235?	127	151	<183	141	306	166	179	81

	2005	2006	2007	2008	2009	2010	2011	2012	2013
Pink-footed goose									
Closed moulting area and further east	17	27	0	0	1	10	17	37	42
Coast west of closed area	0	3	2	0	0	0	0	0	0
Upper Zackenberg valley	0	1	0	2	1	0	6	32	44
Pink-footed goose total	17	31	2	2	2	10	23	69	86
Barnacle goose									
Closed area at Lomsø and Kystkærene	87	148	66	106	70	80	48	77	62
Coast east of closed area	2	218	46	125	77	13	0	25	120
Coast west of closed area	29	29	106	65	34	0	66	35	77
Upper Zackenberg valley	25	30	6	41	51	0	0	69	0
Barnacle goose total	143	425	224	337	232	93	114	206	259

were flying over the research station 8 June (day 159). Between 8 June and 21 June (day 159-172), the first northbound migration bout came, and after a day with few birds migrating, the main northbound bout started 23 June (day 174) until 27 June (day 178). There was no real break between this bout and the start of the southbound bout, which kicked off 6 August. From 11 August, numbers were very low. A total of 4049 birds were recorded; 622 of these, on southbound migration in August and September. These numbers are higher than usual, but we are cautious to make any comparisons due to the unsystematic nature of the data.

The 86 immature pink-footed geese found moulting in the Zackenberg area in 2013 are the highest number since 1999 (table 4.21).

The first common eiders *Somateria mollissima* observation was 16 July (day 196); three females. No eider ducklings were recorded in 2013. Common eiders were seen in flocks of up to 65 individuals from late July into late August. One late flock of 23 common eiders was seen 23 September (day 266).

The first king eiders *Somateria spectabilis* observed was two pairs 16 June (day 167). One nesting attempt was recorded, but no ducklings were seen in 2013. The latest king eiders observation was a flock of five 9 July (day 190).

Long-tailed ducks *Clangula hyemalis* were seen from 6 June (day 157), afterwards pairs were seen almost daily until the late August. Two nests were found (unknown fates), but no ducklings was recorded. The last two long-tailed ducks were seen 23 August (day 235).

Gyr falcons *Falco rusticolus* are rarely seen during summer, but during autumn, especially juveniles, tend to visit the area several times. In 2013, the first gyr falcon was seen 3 July (day 184). During August, September and October, adults were observed several times in the valley. The last gyr falcon, an adult, was recorded at Zackenberg 12 October (day 285).

A northern wheatear *Oenanthe oenanthe* was first photographed by an automatic camera at a fox den 24 May (day 144), just outside the bird census area. On 6 August (day 218), an adult was seen at the research station.

As in recent years, two common raven *Corvus corax* pairs occupied each their territories, with home ranges well beyond the BioBasis census area. Nesting is believed to take place outside the study area. The first observation of five juvenile birds was made 25 June (day 176). Five juvenile birds were seen regularly around the research station and lower part of the valley; the last recording was a single juvenile 20 July (day 201). Adults were recorded in the valley (single individuals only) twice later in August, and then a late observation of a single adult; 1 October (day 274).

Visitors and vagrants

In table 4.22, we present data on avian visitors and vagrants. Two observations of Canada geese, all thought to be the larger subspecies *interior*: 15 June (day 166) one flying northwards, and 30 June (day 181) a flock of four standing in the largest fen of the valley. One vocalising Eurasian golden plover *Pluvialis apricaria* was seen 5 June (day 156) in the fen Tørvekæret.

A single Arctic skua *Stercorarius parasiticus* was recorded 16 July (day 197) near Pashuset; outside the census area, but in the closed goose protection area. A black-legged kittiwake *Rissa tridactyla* was seen late in June near the mouth of the river Zackenberg.

During windy weather, two observations of Arctic terns *Sterna paradisaea* were made. On 28 June (day 179), a single Arctic tern flew over the research station, while a flock of six were recorded flying past the station along the river Zackenberg.

Sandøen

BioBasis only made one short visit to Sandøen during the breeding season in 2013. We looked for nests of Arctic terns *Sterna paradisaea*, Sabine's gull *Larus sabini* and common eider within the central survey square set up in 2006 (cf. Tøttrup and Levermann 2007). One Arctic tern nest (with 2 eggs) and three abandoned common eider nests was recorded within the area 29 July (day 210).

Daneborg

At Daneborg, the common eider colony between the sledge dog pens had below average numbers of nests: 2178 nests (Sirius Patrol, pers. comm.; 2002-2012 average nest numbers: 2377). The colony is the largest in Greenland (Meltofte 1978).

4.4 Mammals

The mammal monitoring programme was conducted by Palle Smedegaard Nielsen, Lars Holst Hansen, Jannik Hansen and Jakob Humaidan. The station personnel and visiting researchers did supplemental observations during the entire field season.

Table 4.22 Numbers of individuals and observations of avian visitors and vagrants at Zackenberg 2013, compared with the numbers of individuals observed in previous seasons, 1995-2012. Multiple observations reasonably believed to have been of the same individual have been reported as one individual.

Visitors and vagrants	Previous records																		2013	
Species	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**No. of ind.**	**No. of obs.**
Great northern diver	0	0	0	0	0	0	1	0	0	0	0	0	2	2	0	1	0	0	0	0
Wooper swan	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Greylag goose	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Snow goose	0	0	0	0	0	2	11	0	23	0	0	0	1	0	0	0[a]	0	4	0	0
Canada goose	0	0	0	0	0	0	0	0	0	0	0	4	3	0	1	0	2	0	5	2
Merlin	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gyr falcon	1	1	1	3	0	4	5	1	3	4	2	0	3[b]	3[c]	4	3	3	5	5[d]	9
Pintail duck	0	0	0	1[e]	0	0	0	0	0	0	0	0	3[e]	0	0	3	0	0	0	0
Common teal	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Eurasian golden plover	0	3	1	3	1	0	3[f]	1	0	1	1	1	1	1	2	2	0	0	1	1
White-rumped sandpiper	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
Pectoral sandpiper	0	0	0	1	0	0	0	2	0	0	0	1	1	0	1	1	0	0	0	0
Purple sandpiper	0	0	0	0	0	0	0	1[g]	0	0	0	0	0	0	0	0	0	1	0	0
Red phalarope	0	0	0	4-5[f]	0	0	4[f]	0	1	0	2[f]	11[f]	0	2	0	2	0	3	0	0
Common snipe	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
Whimbrel	0	0	0	0	0	1	1	0	0	2	1	0	1	2	0	0	0	1	0	0
Eurasian curlew	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Redshank	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Lesser yellowlegs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1[h]	0	0	0
Pomarine skua	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	5	0	0
Arctic skua	0	0	11	6	0	2	7	4	3	2	0	1	0	0	0	0	0	0	1	1
Great skua	0	0	0	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Lesser black-backed gull	0	0	0	0	0	0	1	0	1	2	1	4	0	0	0	0	1	2	0	0
Iceland gull	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	3	0	0
Great black-backed gull	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0
Black-legged kittiwake	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	1	1
Arctic tern	≈200	2	1	2	0	14	0	0	32	0	0	0	0	57	0	0	0	0	7	2
Snowy owl	0	0	2	1	1	1-2	≥4[e]	0	0	0	0	0	1b	0	0	0	0	0	0	0
Meadow pipit	0	0	0	1	0	0	0	0	0	0	1[e]	1[e]	0	0	0	0	0	0	0	0
White wagtail	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Bohemian waxwing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2[g,j]	0	0
Lapland longspur	0	0	0	0	1-2	0	1	0	0	0	1	0	0	0	0	2[f]	3[f]	2	1	1

[a]Two outside census area; [b]See Hansen et al. 2010; [c]Some observations could be double counts, but we estimate numbers between 1 and 3 individuals; [d]Some observations could be double counts, but we estimate numbers between 5 and 7 individuals; [e]Northernmost records in East Greenland (cf. Bortmann 1994); [f]At least one territory, possible territory or breeding found; [g]Juveniles; [h]4th record in Greenland, first in N.E. Greenland; [i]One dead individual found: [j]5th observation in Greenland

The collared lemming *Dicrostonyx groenlandicus* census area was surveyed for winter nests during July and August. When weather permitted, arctic hares *Lepus arcticus* in the designated monitoring area on the south-east and east facing slopes of the mountain Zackenberg were censused during the period 6 July – 27 August. The total numbers of musk oxen, including sex and age classification of as many individuals as possible, were censused weekly within the 47 km² census area from July to October.

The 16 known arctic fox *Vulpes lagopus* dens (number 1-10 and 12-17) within the central part of the Zackenberg valley were checked approximately once a week for occupancy and breeding. The 29 fixed sampling sites for predator scats and casts were checked in late August. Observations of other mammals than collared lemming, arctic fox, musk ox and arctic hare are presented in the section 'Other observations' below. For the eighth year in a row, BioBasis collected arctic fox scats for the analysis of parasitic load.

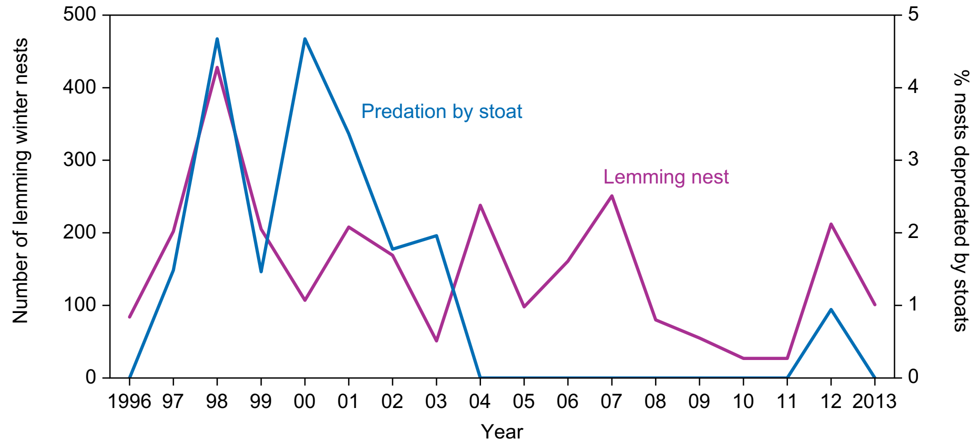


Figure 4.3 Number of collared lemming winter nests registered within the 1.06 km² designated lemming census area (purple line), along with the percentage of winter nests taken over by stoats (blue line) 1996-2013.

Collared lemming *Dicrostonyx groenlandicus*

In 2013, a total of 101 collared lemming nests from the previous winter were recorded within the 1.06 km² census area (table 4.23), which is relatively low. No nests were found to have been depredated by stoat during the 2013 season (figure 4.3). Only one lemming was observed in the field by a bird observer.

Table 4.23 Annual numbers of collared lemming winter nests recorded within the 1.06 km² census area in the Zackenberg valley 1996-2013 together with the numbers of animals encountered by one person with comparable effort each year within the 15.8 km² bird census area during June-July.

Year	New winter nests	Old winter nests	Animals seen
1996	84	154	0
1997	202	60	1
1998	428	67	43
1999	205	36	9
2000	107	38	1
2001	208	13	11
2002	169	20	4
2003	51	19	1
2004	238	15	23
2005	98	83	1
2006	161	40	3
2007	251	21	1
2008	80	20	4
2009	55	9	0
2010	27	23	0
2011	27	3	0
2012	212	20	6
2013	101	14	0

Musk ox *Ovibos moschatus*

Based on the weekly field censuses, table 4.24 lists the sex and age composition over the seasons during July and August. The mean number of animals per count was 95.1. Figure 4.4 illustrates the temporal development in the proportions of the different sex and age classes during the 2013 season. Two year olds and yearling were low in proportion throughout the season. A different trend to previous years was seen with the composition of sex and age classes being rather stable over the season.

Only one fresh musk ox carcass (one adult female) was found during the 2013 season (table 4.25). In addition, two adult males that may have been overlooked in 2012 were found.

Figure 4.4 Sex and age composition of musk oxen registered during the weekly field censuses within the census area during the 2013 season (for the counts from day 249 onwards, only a part of the area was censused due to length of daylight).

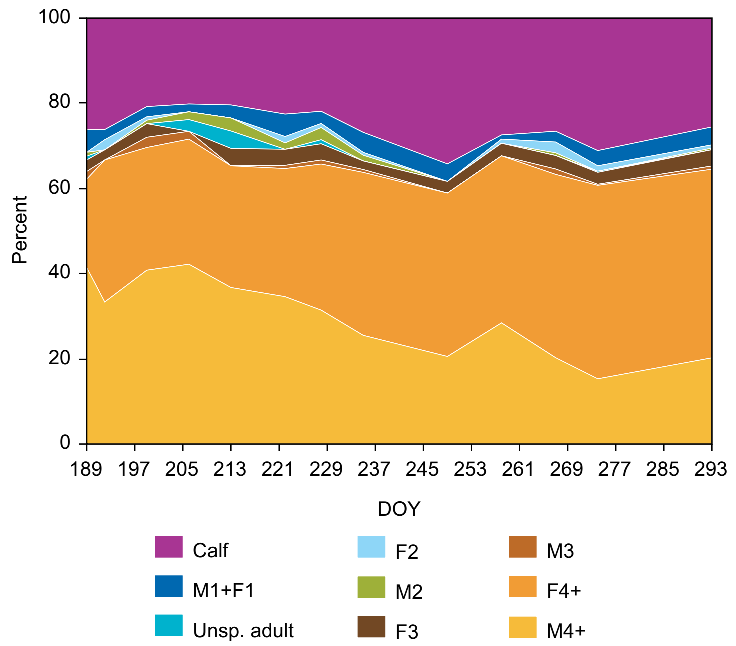


Table 4.24 Sex and age composition of musk oxen based on weekly counts within the 47 km² census area in the Zackenberg valley from July – August 1996-2013.

Year	M4+		F4+		M3		F3		M2		F2		1M+1F		Calf		Unsp. adult		No. of weekly counts
	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	Total	%	
1996	98	14	184	27	7	1	31	5	54	8	17	3	146	22	124	18	15	2	9
1997	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
1998	97	29	97	29	22	7	19	6	30	9	27	8	14	4	22	7	1	0	8
1999	144	38	106	28	21	6	21	6	9	2	12	3	5	1	30	8	32	8	8
2000	109	30	118	32	11	3	15	4	2	1	7	2	31	8	73	20	3	1	8
2001	127	30	120	29	8	2	19	5	26	6	19	5	43	10	55	13	4	1	7
2002	114	20	205	36	20	3	24	4	38	7	43	8	51	9	77	13	0	0	8
2003	123	23	208	39	24	5	23	4	16	3	19	4	44	8	72	14	0	0	8
2004	122	22	98	18	13	2	28	5	5	1	8	1	32	6	124	23	119	22	7
2005	212	23	260	28	11	1	46	5	43	5	21	2	116	13	200	22	6	1	9
2006	205	29	123	17	29	4	55	8	62	9	34	5	102	14	94	13	0	0	7
2007	391	25	341	22	73	5	152	10	80	5	83	5	202	13	246	16	8	1	9
2008	267	34	189	24	38	5	57	7	44	6	58	7	58	7	63	8	18	2	8
2009	269	42	176	28	32	5	38	6	32	5	23	4	30	5	18	3	21	3	8
2010	246	49	101	20	40	8	26	5	29	6	21	4	8	2	18	4	15	3	9
2011	267	46	181	31	24	4	16	3	6	1	12	2	11	2	53	9	8	1	8
2012	235	56	106	25	16	4	17	4	16	4	9	2	8	2	10	2	1	0	9
2013	264	35	243	32	8	1	21	3	13	2	6	1	26	3	172	23	8	1	8

Table 4.25 Fresh musk oxen carcasses found during the field seasons 1995-2013. F=female, M=male.

Year	Total carcasses	4+ yrs F/M	3 yrs F/M	2 yrs F/M	1 yr	Calf
1995	2	0/1				1
1996	13	7/1	0/1	0/2	2	
1997	5	0/2		1/0	1	1
1998	2	0/2				
1999	1	0/1				
2000	8	0/6	1/0			1
2001	4	0/4				
2002	5	1/2	1/0			1
2003	3	0/2				1
2004	2	1/1				
2005	6	2/3				1
2006	5	0/2			1	2
2007	12	3/4	1/0		1	3
2008	10	3/1	2/0			4
2009	16	5/3				8
2010	6	2/1	0/1			2
2011	5	2/3				
2012	27	1/8	0/3		3	12
2013	1	1/0				

Arctic fox *Vulpes lagopus*

In 2013, breeding was verified in three fox den complexes and a total number of 12 Arctic fox pups were observed at their maternal den complexes (table 4.26).

Arctic hare *Lepus arcticus*

In 2013, 16 counts with good visibility were carried out during July and August with a mean of 3.9 Arctic hares per census (table 4.27).

Other observations

Polar bear *Ursus maritimus* was observed in the central research area on two occasions in 2013. An adult bear was observed 23 June southwest of the station. It disappeared in a south-eastern direction. The second bear was observed 30 June near the musk ox exclosures where it damaged one of the time lapse cameras. It later destroyed an insect trap before leaving the valley in a south-eastern direction. Observers at both instances have judged these to be two different bears based on the condition of the fur. In addition, one adult male bear was observed at Pashyt-

Table 4.26 Numbers of known fox breeding den complexes checked, number of active breeding den complexes and total number of pups recorded at their maternal den complex within and outside the central part of the Zackenberg valley 1995-2013. Photos from automatic cameras showed additional four and nine pups in 2008 and 2012 respectively. W=white phase and D=dark phase.

Year	No. of known den complexes checked inside/outside	No. of active breeding den complexes inside/outside	Total no. of pups recorded at their maternal den complex
1995	2/0	0/0	0
1996	4/0	2/0	5W + 3D
1997	4/0	0/0	0
1998	2/0	1/0	5W
1999	4/0	0/0	0
2000	5/0	3/0	8W
2001	6/2	3/2	16W + 1D
2002	6/2	0/0	0
2003	6/1	5/0	21W
2004	6/2	5/1	20W
2005	6/2	0/0	0
2006	6/2	3/1	17W
2007	6/2	5/1	23W
2008	6/2	5/1	20W
2009	6/2	3/0	10W
2010	7/2	3/0	15W
2011	7/2	3/0	8W
2012	7/2	5/0	23W + 2D
2013	7/2	3/0	10W + 2D

Table 4.27 Numbers of Arctic hares within the designated census area per observation day counted during July and August 2013.

Year	Counts	Average	SD	Range
2001	22	1.2	1.3	0-5
2002	16	0.4	0.6	0-2
2003	20	2.4	1.8	0-6
2004	23	0.9	1.1	0-3
2005	48	5.5	5.1	0-26
2006	39	5.9	3.7	1-19
2007	18	4.8	3.0	0-11
2008	17	2.5	2.3	0-7
2009	16	4.8	2.8	1-12
2010	18	3.1	1.9	0-7
2011	14	2.7	1.7	1-7
2012	14	4.3	2.2	2-9
2013	16	3.9	2.3	0-8

ten (small hut) 28 July where it swam by the small hut before going ashore at the river Cardioceras. It followed the riverbed upstream. Again by Pashytten, 6 August, an adult bear was observed from a boat. This bear could very well be one that was reported at Daneborg during summer.

In 2013, an adult Arctic wolf *Canis lupus* was briefly seen in Zackenberg in area 1C chasing geese on one occasion in July. The observation was confirmed by tracks on the beach.

No stoats *Mustela erminea* or tracks were observed in 2013, and no new lemming winter nests found in the census area showed sign of predation by stoats. During the standardised collection of scats and casts, no stoat scat was found (table 4.29).

BioBasis did one landing on Sandøen 29 July, where 11 walruses *Odobenus rosmarus* were observed hauling out and an additional four were in the water close to the beach. Walrus were also observed on the broken up ice in the river Zackenberg delta 19 July and swimming in Young Sund near Pashytten 28 July.

Collection of wildlife samples

Tissue samples from dead vertebrate species encountered in the field were collected (table 4.28). Also, scats and casts were collected at 29 permanently marked sites in the valley (table 4.29).

Table 4.28 Wildlife specimens collected for tissue samples in 2013 and all seasons collectively.

Species	2013	1997-2013
Arctic char	5	11
Arctic fox	2	15
Arctic hare	0	16
Collared lemming	1	10
Common raven	0	2
Dunlin	0	5
Glaucous gull	0	1
Gyr falcon	0	1
Musk oxen	2	102
Northern wheatear	0	1
Rock ptarmigan	0	3
Ruddy turnstone	0	1
Seal (sp.)	0	1
Three-spined stickleback	0	6
Fourhorn sculpin	0	5
Snow bunting	0	2
Lapland bunting	0	1
Barnacle goose	0	2

Table 4.29 Numbers of casts and scats from predators collected from 29 permanent sites in the Zackenberg valley. The samples represent the period from mid/late August the previous year to mid/late August in the year denoted.

Year	Fox scats	Stoat scats	Skua casts	Owl casts
1997	10	1	44	0
1998	46	3	69	9
1999	22	6	31	3
2000	31	0	33	2
2001	38	3	39	2
2002	67	16	32	6
2003	20	1	16	0
2004	16	3	27	0
2005	24	0	7	6
2006	29	0	15	4
2007	54	4	13	3
2008	30	1	16	0
2009	22	2	11	1
2010	22	1	3	0
2011	28	7	15	1
2012	23	1	21	1
2013	6	0	10	1

4.5 Lakes

The two fairly small lakes, Sommerfuglesø and Langemandssø, situated in Morænebakkerne are included in the BioBasis monitoring programme. A series of physical, chemical and biological parameters are sampled during approximately four months, which include the ice free summer period (July-August) as well as the end and beginning of the ice covered periods (i.e., June and September). In 2013, the sampling took place from 20 June to 12 October and included six sampling dates. Furthermore, surveillance cameras mounted on a mast at the hill between the two lakes and facing towards each of the lakes, have taken pictures of the lake surface twice during a 24 hour cycle on a full year basis. These pictures are used to follow the changes in the snow cover and to help identify the exact duration of the ice coverage period.

The lakes became ice-covered during the first part of September 2012 and due to stable weather condition the initial ice layer stayed intact for the rest of the autumn. Snow accumulated during winter and covered both lakes from January and onwards. Based on the cameras (see examples in figures 4.5 and 4.6) as well as visual inspections by binoculars from the slopes of Aucellabjerg it was observed, that both lakes had lost 50 % of the ice coverer by 15 June. Compared to previous years this appears as an early melt but was in accordance with the low snow depth and coverage in the entire valley (see section 4.1). The first sampling could therefore be carried out 20 June where both lakes were ice-free (1 % ice was still present at Langemandssø). The lakes became ice-covered again in mid-September (table 4.30) which means that the main growing season in 2013 lasted approximately 85 days.

Since 2013 was characterized by an early ice-off date and was followed by a warm July and August it implied that lake water temperatures of 12-13 °C was recorded during summer (table 4.30). The mean temperatures for the entire summer period were 11.3 and 10.0 °C in Sommerfuglesø and Langemandssø, respectively (table 2013-1). Thus, the main growing season was on average warmer than most previous year especially in Langemandssø (tables 4.31 and 4.32).

The basic water chemistry included measurement of total nitrogen and total phosphorus, conductivity and pH (table 4.30). On average (summer values) these parameters were within the levels recorded during the previous years (tables 4.31 and 4.32) but with a high conductivity and a high total nitrogen concentration. The same was observed for the autumn period. Contrary to previous years the concentrations of total phosphorous and pH remained at the same levels during the autumn (table 4.30). Whether this could be caused by a slow decrease of the active layers surrounding the lakes is not known.

The chlorophyll *a* concentration in the water column reflects the pelagic algae biomass and was 0.5 and 0.3 µg l^{-1} in Sommerfuglesø and Langemandssø, respectively, during summer. Although the intra-annual chlorophyll concentration varies by a factor of around four it appears as a low level in comparison with previous years (tables 4.31 and 4.32). However, the chlorophyll concentrations decreased to even lower levels in both lakes later in the season (table 4.30). The low concentrations during summer reflects probably a combination of low nutrient availability and grazing by zooplankton while the reason for low autumn concentrations is not clear as the grazers of phytoplankton were low in numbers in the autumn (see table 4.36). The increased concentration in the late autumn (October) may be a consequence of the increased nutrient concentrations as indicated by the increased conductivity mentioned above.

Figure 4.5 Photo taken on 15 June 2013 by the surveillance camera facing towards Langemandssø.

Figure 4.6 Photo taken on 15 June 2013 by the surveillance camera facing towards Sommerfuglesø.

Table 4.30 Physico-chemical variables and chlorophyll a concentrations in Sommerfuglesø (SS) and Langemandssø (LS) during June-October 2013.

Lake	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**
Date 2013	**171**	**195**	**215**	**236**	**265**	**285**	**171**	**195**	**215**	**236**	**265**	**285**
Ice cover (%)	0	0	0	0	100	100	1	0	0	0	85	100
Temperature (°C)	12.2	9.8	12.7	6.7	3.3	1.1	8.5	9.8	12.8	6.1	1.0	0.3
pH	6.7	6.7	6.8	6.8	6.6	6.4	6.6	6.3	6.7	6.7	6.6	6.5
Conductivity (µS cm^{-1})	18.7	33.7	35.1	39.6	44.5	46.3	16.9	21.7	23.2	32.6	40.2	48.3
Chlorophyll *a* (µg l^{-1})	0.24	0.34	0.45	0.60	0.25	0.25	0.14	0.23	0.22	0.46	0.38	0.37
Total nitrogen (µg l^{-1})	270	230	640	320	280	180	180	270	260	240	160	160
Total phosphorous (µg l^{-1})	3	3	12	7	<1	<1	6	8	7	8	<1	<1

Table 4.31 Average physico-chemical variables in Sommerfuglesø (SS) in 1999-2013 (July-August) as well as single values from mid-August 1997 and 1998. ND = no data.

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Date of 50% ice cover	ND	192	199	177	183	184	175	176	169	186	166	181	179	165	176	179	166
Temperature (°C)	6.3	6.5	6.1	10.1	8.4	8.3	11	8.7	9.8	10.1	10	10.6	9.5	10.4	10.8	7.2	11.3
pH	6.5	7.4	6.7	5.8	6.6	6	6.5	6.3	6	6.2	6.6	5.9	6.7	6.7	6.6	6.7	6.8
Conductivity (µS cm^{-1})	15	13	10	18	18	8	12	15	22	11	10	16	22	18	22	23	36
Chlorophyll *a* (µg l^{-1})	0.84	0.24	0.41	0.76	0.67	1.27	1.84	1.62	1.59	0.65	1.49	0.57	0.89	1.26	0.50	0.59	0.46
Total nitrogen (µg l^{-1})	ND	130	210	510	350	338	277	267	263	293	323	238	298	248	220	193	397
Total phosphorous (µg l^{-1})	4	9	11	10	19	11	11	7	9	8	10	6	7	5	8	6	7

Table 4.32 Average physico-chemical variables in Langemandssø (LS) in 1999-2013 (July-August) as well as single values from mid-August 1997 and 1998. ND = no data.

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Date of 50% ice cover	ND	204	202	182	189	187	183	178	173	191	167	182	172	174	178	184	166
Temperature (°C)	6.8	6.4	4	9.5	8.4	8.1	11.1	9.1	10.5	9.8	10.6	8.8	9.1	9.2	11.4	6.7	9.6
pH	6.5	7	6.3	5.5	6.4	5.5	6.1	6.1	6	6.3	6	5.7	6.5	6.6	6.7	6.6	6.6
Conductivity (μS cm^{-1})	8	9	7	9	8	6	6	8	14	5	7	7.8	18	15	31	20	26
Chlorophyll *a* (μg l^{-1})	1.04	0.32	0.38	0.9	1.46	2.72	3.14	0.98	1.62	0.56	1.54	0.92	1.06	1.20	0.60	0.95	0.30
Total nitrogen (μg l^{-1})	ND	80	120	290	340	387	237	230	247	203	268	138	172	208	227	230	257
Total phosphorous (μg l^{-1})	8	7	7	11	20	13	10	11	11	6	8	6	9	10	4	7	8

Table 4.33 Biovolume (mm^3 l^{-1}) of phytoplankton groups in Sommerfuglesø and Langemandssø during June-October 2013.

Lake	SS	SS	SS	SS	SS	SS	LS	LS	LS	LS	LS	LS
Date 2013	171	195	215	236	265	285	171	195	215	236	265	285
Nostocophyceae	0.001						0.000	0.000	0.002	0.000	0.003	
Dinophyceae	0.022	0.233	0.529	1.123			0.106	0.098	0.067	0.194	0.041	0.010
Chrysophyceae	0.792	0.555	0.467	0.437	0.100	0.074	0.139	0.203	0.399	0.083	0.252	0.510
Diatomophyceae	0.006	0.005	0.006				0.001	0.001	0.001	0.004		
Chlorophyceae	0.001	0.002	0.005	0.001			0.010	0.024	0.048	0.018	0.000	
Others					0.010							0.004
Total	0.821	0.795	1.008	1.561	0.110	0.074	0.256	0.326	0.517	0.299	0.296	0.524

Table 4.34 Average biovolume (mm^3 l^{-1}) of phytoplankton groups in Sommerfuglesø during summer (July and August) from 1997 to 2013 (note that some years are missing).

Year	1998	1999	2001	2002	2003	2005	2006	2007	2008	2009	2010	2011	2012	2013
Nostocophyceae	0	0.005	0	0	0	0	0	0	0	0	0	0	0.002	0
Dinophyceae	0.034	0.044	0.015	0.006	0.027	0.185	0.068	0.113	0.184	0.053	0.248	0.590	0.242	0.628
Chrysophyceae	0.022	0.096	0.358	0.066	0.237	0.554	0.145	0.386	0.092	0.261	0.303	0.089	0.034	0.486
Diatomophyceae	0.002	0	0.001	0	0	0	0.007	0	0	0.003	0.005	0.001	0.003	0.006
Chlorophyceae	0.005	0.002	0	0	0.002	0.009	0.004	0.001	0	0	0	0.001	0	0.003
Others	0	0	0.004	0	0	0	0	0	0	0.002	0	0	0	0
Total	0.063	0.147	0.377	0.073	0.266	0.749	0.223	0.499	0.276	0.319	0.555	0.680	0.280	1.123

Table 4.35 Average biovolume (mm^3 l^{-1}) of phytoplankton groups in Langemandssø during summer (July and August) from 1997 to 2013 (note that some years are missing).

Year	1997	1998	1999	2001	2002	2003	2005	2006	2007	2008	2009	2010	2011	2012	2013
Nostocophyceae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.001
Dinophyceae	0.291	0.185	0.305	0.04	0.156	0.123	0.03	0.068	0.05	0.222	0.095	0.118	0.094	0.78	0.120
Chrysophyceae	0.066	0.187	0.048	0.592	0.377	0.358	0.296	0.318	0.192	0.262	0.424	0.48	0.184	0.155	0.228
Diatomophyceae	0.002	0	0	0.002	0	0	0	0.009	0	0	0	0	0.002	0.003	0.002
Chlorophyceae	0.016	0	0.002	0.002	0	0.003	0.019	0.008	0.017	0.004	0.013	0.099	0.038	0.036	0.030
Others	0	0	0	0	0	0	0	0	0	0	0	0		0	0.000
Total	0.375	0.372	0.354	0.637	0.533	0.484	0.345	0.404	0.259	0.487	0.532	0.697	0.316	0.271	0.381

The phytoplankton communities were, as is usually the case for arctic lakes, dominated by dinophytes and chrysophytes (table 4.33) during most of the season in Sommerfuglesø and Langemandssø, respectively. The remaining biomass in both lakes was chlorophytes, chrysophytes and occasionally diatoms. Typical genera were *Gymnodium*, *Peridinium*, *Uroglena*, *Mallomonas* and *Ochromonas*. The results are comparable to findings from previous years (tables 4.34 and 4.35). The phytoplankton diversity and biomass was lowest in the beginning and end of the season, while it peaked during July-August.

The zooplankton community in Sommerfuglesø included cladocerans (*Daphnia pulex*), copepods (*Cyclops abyssorum*) and rotifers (*Polyarthra dolicopthera*). The aver-

Table 4.36 Density (no l-1) of zooplankton in Sommerfuglesø (SS) and Langemandssø (LS) during June-October 2013.

Lake	**SS**	**SS**	**SS**	**SS**	**SS**	**SS**	**LS**	**LS**	**LS**	**LS**	**LS**	**LS**
Date 2013	**171**	**195**	**215**	**236**	**265**	**285**	**171**	**195**	**215**	**236**	**265**	**285**
Cladocera	1.6	5.2	8.8	1.1	0.0	0.1			0.1		0.3	0.6
Copepods	8.6	5.0	2.1	0.7	0.5	0.6	15.3	13.1	17.9	40.0	9.6	3.1
Rotifers	2.5	76.9	5.5	27.4	25.3	2.6	19.0	35.7	5.2	5.9	1.4	0.1
Others												
Total	12.7	87.1	16.4	29.2	25.8	3.3	34.3	48.7	23.1	45.9	11.4	3.9

Table 4.37 Average density (no l-1) of zooplankton species in Sommerfuglesø during summer (July and August) from 1997 to 2013.

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Cladocera																	
Daphnia pulex	0.3	10.5	0.3	6.7	8.2	6.8	7.7	0.7	6.4	7.07	3.8	6.33	2.87	7.8	3.4	4	5.33
Macrothrix hirsuiticornis	0.1	0	0	0	0	0	0	0	0.07	0	0	0	0	0	0	0	0
Chydorus sphaericus	0.05	0	0	0	0.06	0	0	0	0.13	0	0	0	0	0.1	0	0.3	0
Copepoda																	
Cyclops abyssorum alpinus (adult+copepodites)	0.8	0.5	0.5	0.3	0.5	0.2	0.9	0.3	0.07	0.27	2	1.27	0.47	2	1.5	1	1.29
Nauplii	5.7	1.3	6.5	1.1	1.4	2.3	0.3	0.3	0.2	1.67	0.13	1.93	0.07	3.7	6.9	1.7	1.32
Rotifera																	
Polyarthra dolicopthera	171	90	185	97	74	11	0.5	1.87	7.67	42.2	108	49.8	150	45	12.3	5.8	36.5
Keratella quadrata group	4.5	3	17	0	0	0.4	0.1	0	0	0.33	0	0	0	0	0	0.2	0
Conochilus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euchlanis sp.	0	0	0	0	0	0	0	0	0.33	0.07	0	0	1.78	0	0	0	0

age abundance for the summer period was 44 individuals l^{-1} with the largest contribution from rotifers (table 4.36). Langemandssø had average zooplankton densities of 39 individuals l^{-1} but the community consisted only of copepods and rotifers. The difference in species composition between the two lakes is controlled by the population of dwarf-sized Arctic char in Langemandssø and no fish in Sommerfuglesø. The recorded zooplankton species composition as well as densities in the summer period (July-August) was within the range found for previous years (tables 4.37 and 4.38). The low abundance of cladocerans and copepods in the autumn is most likely related to the low food concentration.

No attempts were made to sample the fish population in Langemandssø but during a winter campaign in 2012 it was revealed by a remotely operated vehicle mounted with a camera, that fish were present in the lake.

Summarizing the data from 2013 it follows that the season had been longer than an average season due to an early ice melt and that this affected the biological components to some extent.

Table 4.38 Average density (no l-1) of zooplankton species in Langemandssø from during summer (July and August) 1997 to 2015.

Year	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Cladocera																	
Daphnia pulex	0	0	0	0	0	0	0.1	0	0	0	0	0	0	0	0	0.1	0
Macrothrix hirsuiticornis	0	0	0.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chydorus sphaericus	0	0.1	0	0.5	0.1	0.07	0	0	0.13	0.07	0.07	0	0	0	0.1	0.2	0
Copepoda																	
Cyclops abyssorum alpinus (adult+copepodites)	3.3	2.9	4.1	22	13.4	6.8	8.6	4.9	5.8	11.7	8.93	2.27	14.1	15	13.6	14.1	21.1
Nauplii	5.2	3.8	6.4	3.1	4.5	4.5	4.2	0	2.2	5.13	1.07	3.07	2.27	5.3	5.4	13	2.51
Rotifera																	
Polyarthra dolicopthera	316	330	274	168	248	22	78	71	99	181	40	185	32.7	46.3	9.9	92.1	15.3
Keratella quadrata group	4.5	28	34	0	0	0.3	0	1.3	0	41.3	0	2.6	0	1.3	0	3.3	0
Conochilus sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Euchlanis sp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

5 Zackenberg Basic

The MarineBasis programme

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This chapter presents results from the 11th year of the MarineBasis programme. The programme conducts long-term monitoring of physical, chemical and biological parameters of the coastal marine ecosystem at Zackenberg. The intention is to be able to quantify climate related changes in this high arctic marine ecosystem. The programme is conducted during a three week field campaign in the summer combined with continuous measurements by moored instruments during the rest of the year. Summer measurements are primarily conducted in the outer part of Young Sund but supplemented with data from Tyrolerfjord and the Greenland Sea.

The sampling strategy during summer is to describe the spatial variation in hydrographic parameters by sampling a number of stations once (figure 5.1) and also to determine the day-to-day variation at a single station. The programme includes hydrographic measurements (salinity, temperature, pressure, dissolved oxygen, fluorescence, light profiles and turbidity) combined with determination of nutrient concentrations (NOx, PO_4^{3-}, SiO_4) and surface $p CO_2$. The species composition of phyto- and zooplankton is determined at a single station. On the sea floor, the sediment-water exchange of nutrients, dissolved inorganic carbon (DIC) and oxygen is quantified. In addition, the annual growth rate of the kelp *Saccharina latissima* is estimated. To supplement data collected during summer, a mooring is established in the outer part of Young Sund where continuous measurements of temperature and salinity are conducted at two depths and the vertical flux of sinking particles are estimated throughout the year using a sediment trap.

5.1 Sea ice

The extent and duration of the seasonal ice cover in Young Sund is a major driver of ecosystem processes. The duration of the ice free period in summer is increasing

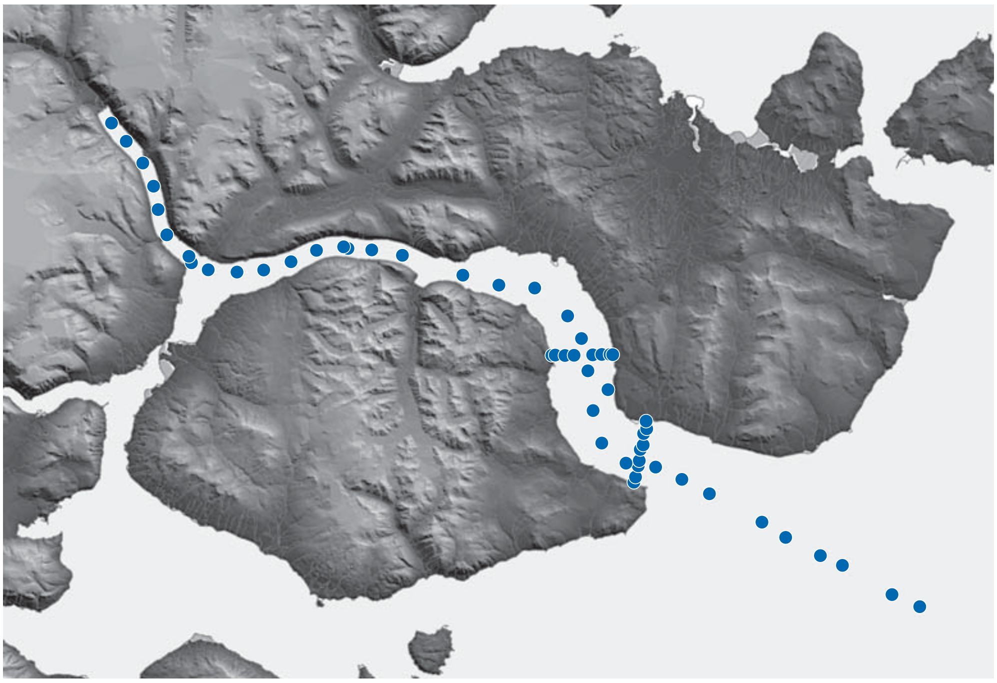
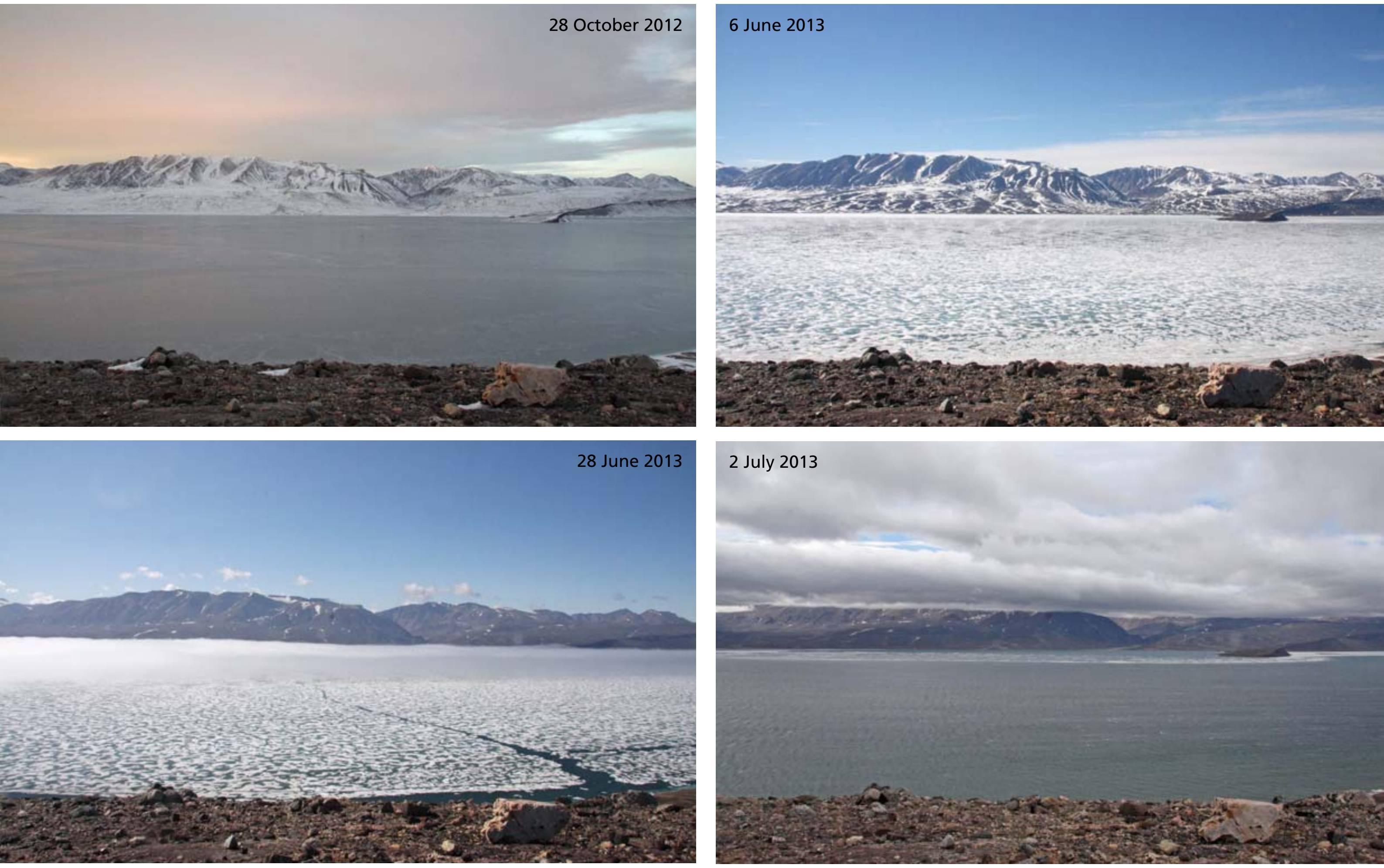


Figure 5.1 Map of the sampling area. The dots represent the hydrographic sampling stations from the innermost Tyrolerfjord on the left to the East Greenland Shelf on the right.



slightly but with a distinct increase in the year to year variability. This variability is primarily related to the date of fast ice formation in autumn whereas the date for ice break up in early summer remains relatively stable. In 2013, the summer break up of sea ice occurred on July 2 (figure 5.2). This is the earliest date recorded since recordings started in 1947. The open water season was 105 days (figure 5.3). Snow cover on the sea ice was very low with a maximum of just 29 cm (table 5.1). The thin snow cover resulted in little isolation of the sea ice from winter temperatures and consequently the sea ice reached a maximum thickness of 175 cm, which is well above the average.

Figure 5.2 Examples of images used to monitor ice conditions in 2012-2013 in outer Young Sund.

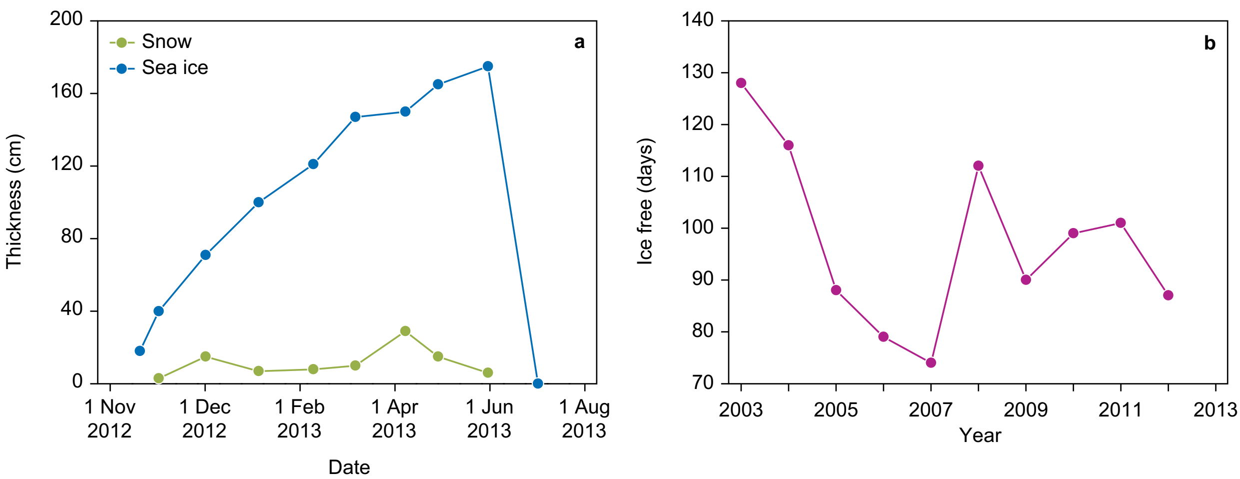


Figure 5.3 Seasonal changes in thickness of sea ice and snow cover (a). Variation in ice free condition in outer Young Sund from 2003 to 2013 (b).

Table 5.1 Summary of sea ice and snow conditions in Young Sund.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Ice thickness (cm)	120	150	125	132	180	176	155	148	144	148	175
Snow thickness (cm)	20	32	85	95	30	138	45	45	20	77	29
Days with open water	128	116	98	75	76	132	90	99	101	87	105*

5.2 Water column

Seasonal data from hydrographic mooring

The hydrographic mooring is used to monitor the seasonal changes in temperature and salinity and to estimate the annual flux of inorganic particles and organic carbon to the seafloor. The mooring was deployed 10 August, 2012 and retrieved again 16 August, 2013. Two CTDs positioned at 29 and 61 m depth recorded temperature and salinity every 20 minutes. Although freshwater from land and melting sea ice enters the fjord from early July, a decrease in salinity at 29 m depth is not observed until late August and minimum salinity is observed in mid-September (figure 5.4A). At 61 m depth the seasonal range in salinity is about 0.5 units with a minimum in April or May. From 2012 to 2013 the salinity showed a slight decrease at both depths. At 29 m depth the decrease was from about 31.7 ‰ in August 2012 to 31.5 ‰ in August 2013. At 61 m depth is was from 32.05 ‰ in 2012 to 31.85 ‰ in 2013. A similar freshening trend has been observed in 2010 and 2011, whereas salinity increased in 2012. The sediment trap collecting both organic and inorganic material functioned as planned but due to analytical problems in the laboratory the samples have not been analysed yet but will be presented later.

Summer distribution of hydrological parameters

The spatial variation in hydrological conditions is quantified by measuring vertical profiles with a CTD along three transects in the fjord; one transect extending from Tyrolerfjord to the Greenland Sea and two transects across the fjord (figure 5.1). The transect extending along the entire fjord showed large spatial differences in the fjord (figure 5.5). Turbidity is governed by the inflow of the major rivers in the fjord.

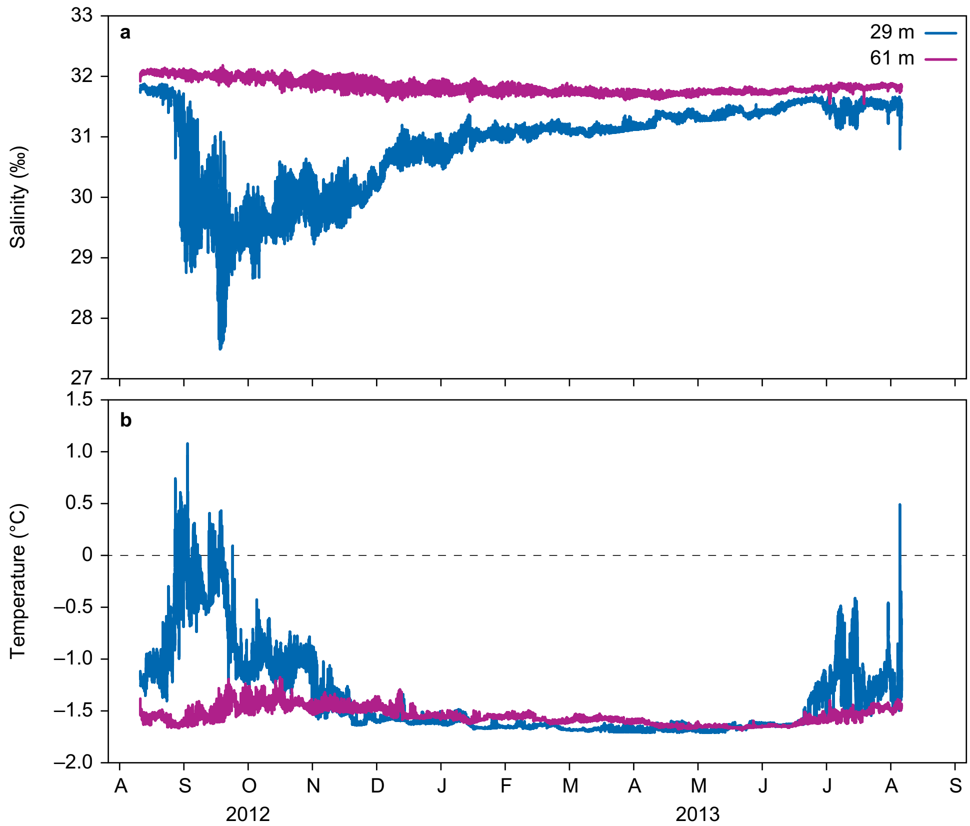


Figure 5.4 Time series of temperature (a) and salinity (b) at two depths in outer Young Sund 2012-2013.

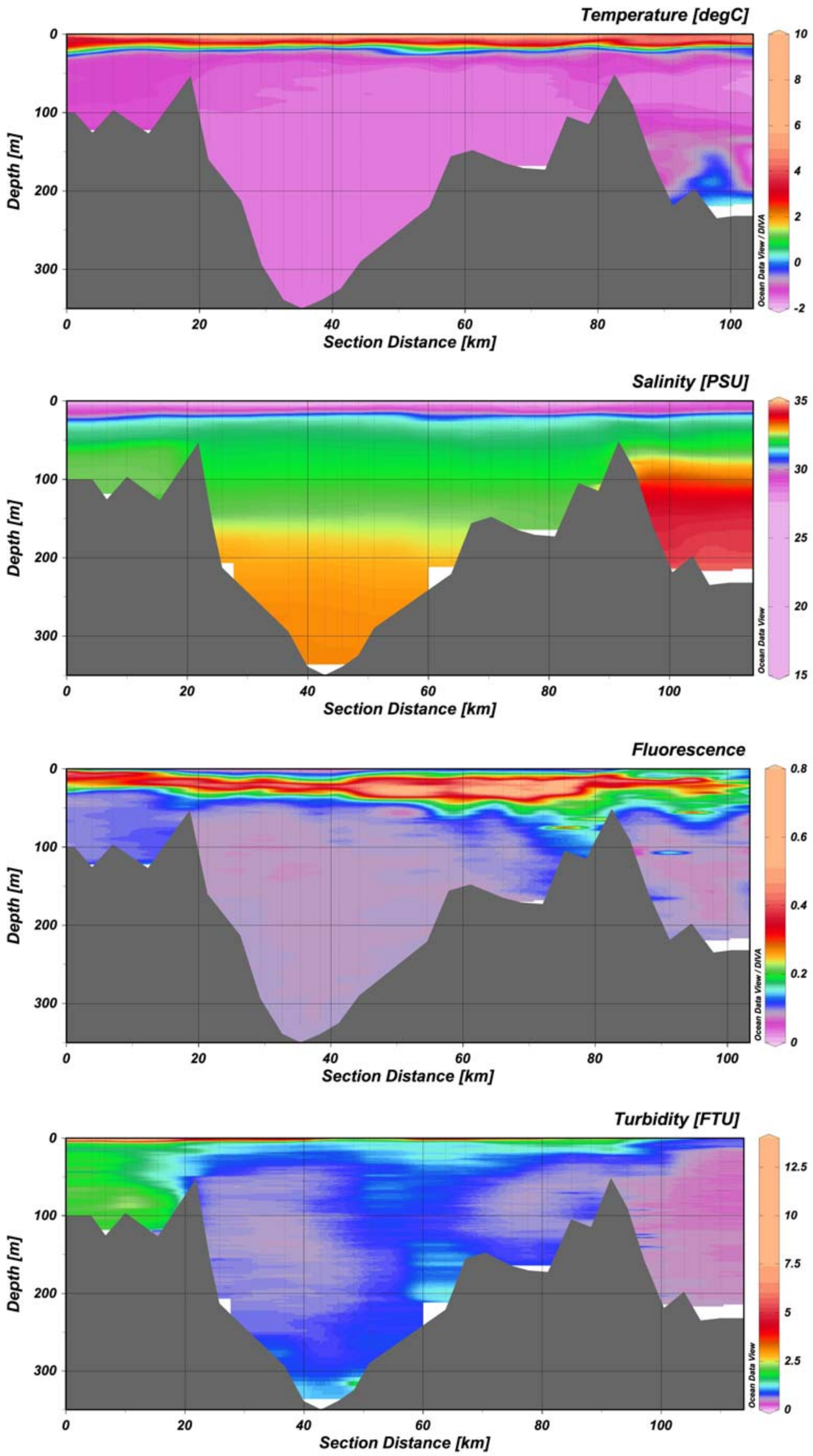


Figure 5.5 Spatial changes in temperature, salinity, fluorescence and turbidity in Tyrolerfjord (left), through Young Sund and into the Greenland Sea (right).

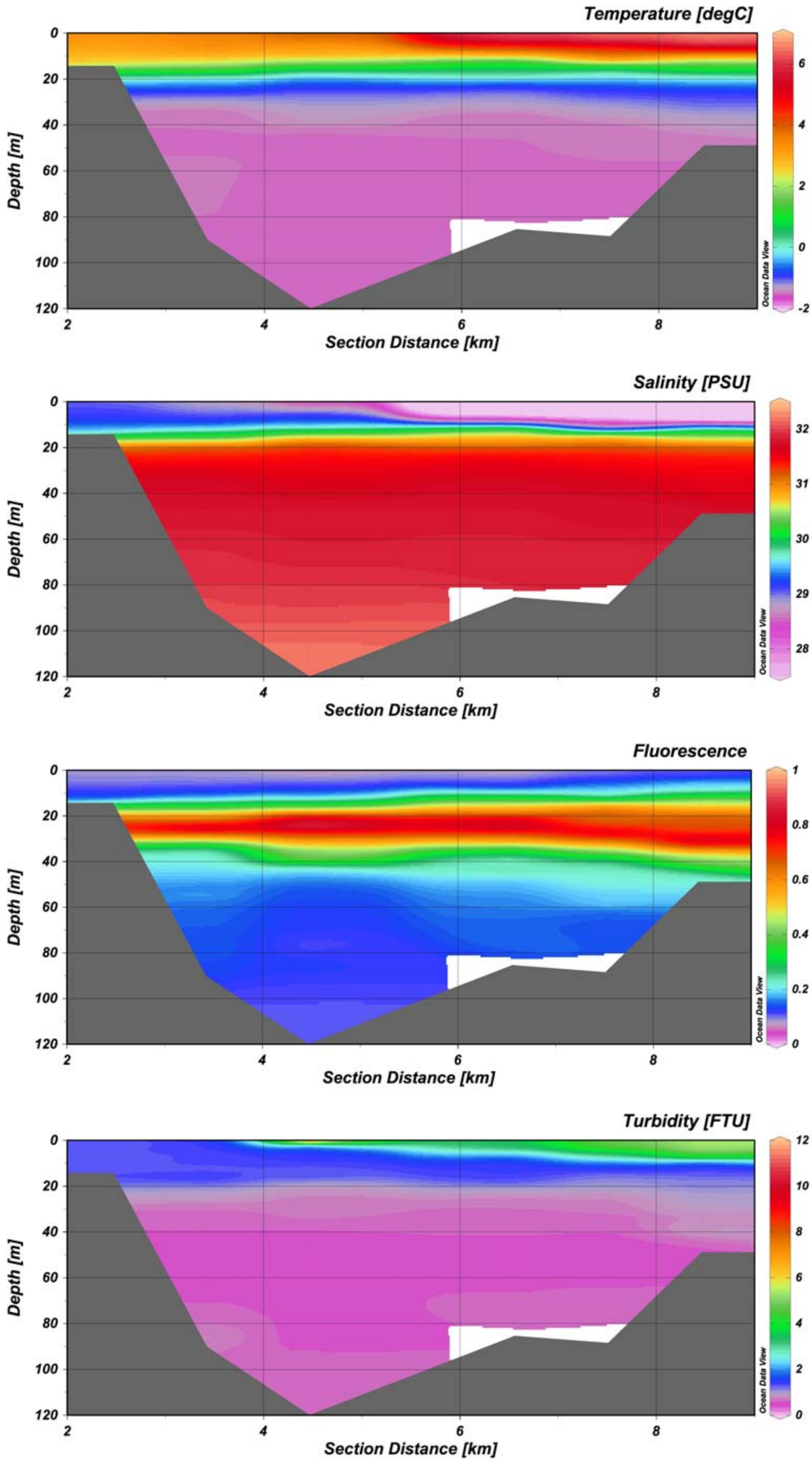


Figure 5.6 Spatial changes in temperature, salinity, fluorescence and turbidity across Young Sund near Basalt Island. Wollaston Forland to the left and Clavering Ø to the right.

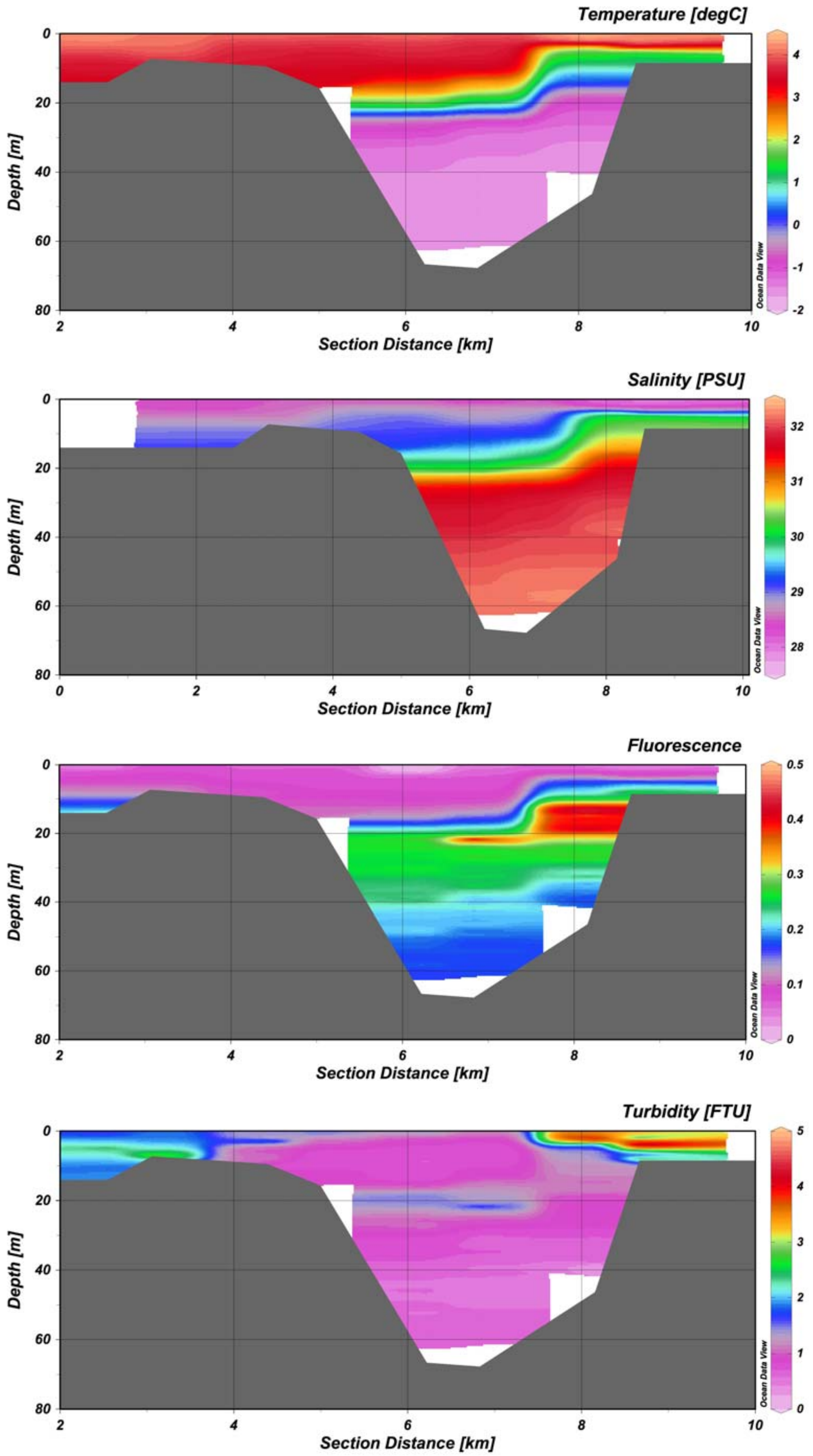


Figure 5.7 Spatial changes in temperature, salinity, fluorescence and turbidity across Young Sund near Sandøen. Wollaston Forland to the left and Clavering Ø to the right.

High turbidity in the entire water column is found in the inner basin in Tyrolerfjord and high surface values are found near Lerbugt Elv and the river Zackenberg. Temperature is very uniform in most of the fjord below 50 m depth, with a slight warming of the inner basin in Tyrolerfjord. In addition, the presence of warm Atlantic water with a temperature around 2 °C on the shelf at depths around 200 m is visible. The contour plot of the salinity in the fjord shows how the sill prevents exchange of high salinity water on the shelf with the fresher water in the central basin of the fjord. Since the beginning of the programme a gradual decrease in salinity has been observed in the deeper part of the fjord. Fluorescence, which is an indicator of chlorophyll *a* concentrations, show maximum, values in the outer part of the fjord where low turbidity increase light conditions for phytoplankton. Maximum values are often found outside the fjord but this year a sub-surface peak in fluorescence was found inside the sill.

Two transects across the fjord is also measured. The inner one is near Basalt Island (figure 5.6). The transect shows how freshwater at the surface flows out of the fjord near the Clavering Island, where surface salinity is less than 26 ‰ compared to the opposite side of the fjord where salinity

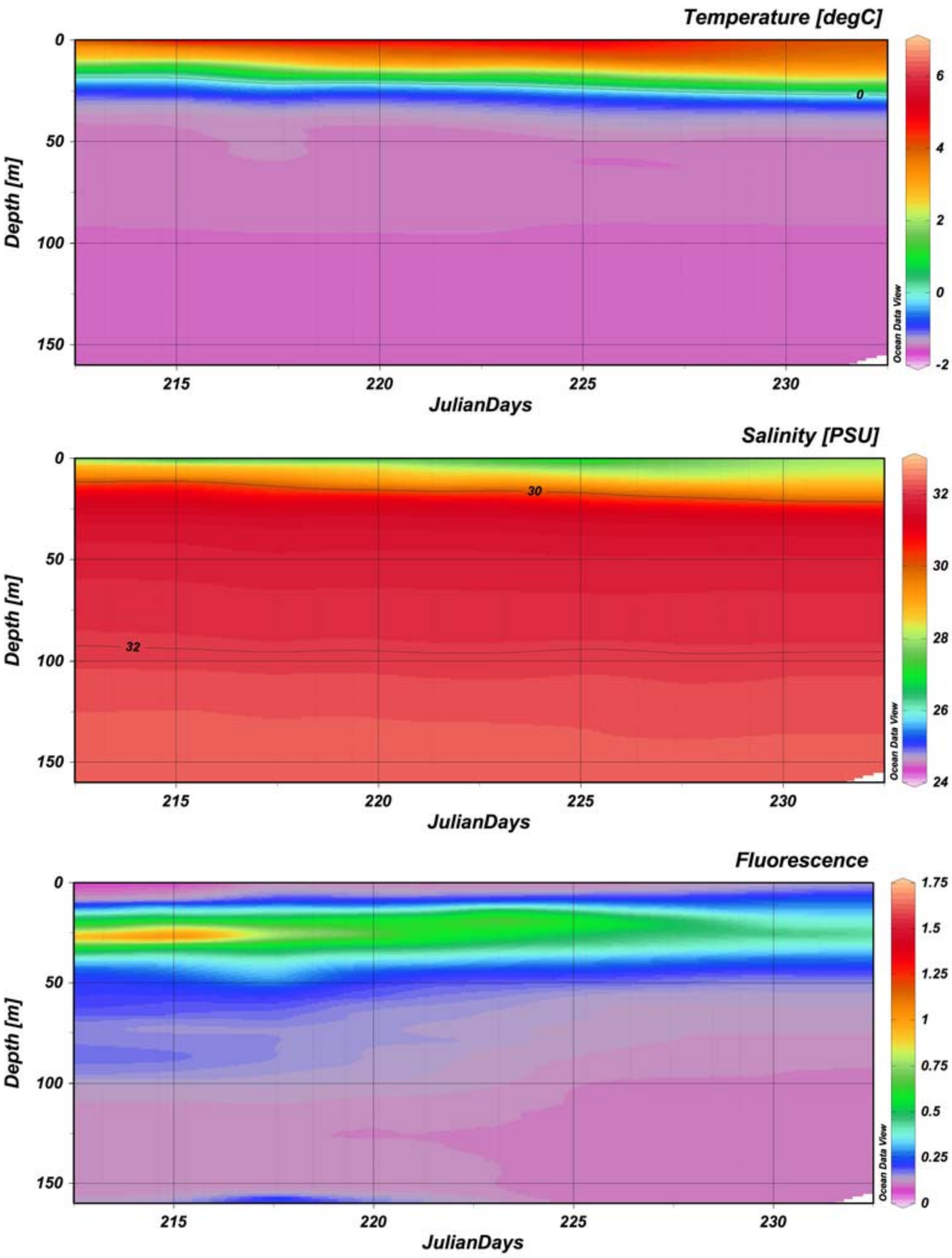


Figure 5.8 Temporal changes in late July and early August in temperature, salinity and fluorescence at the 'Main Station' in outer Young Sund.

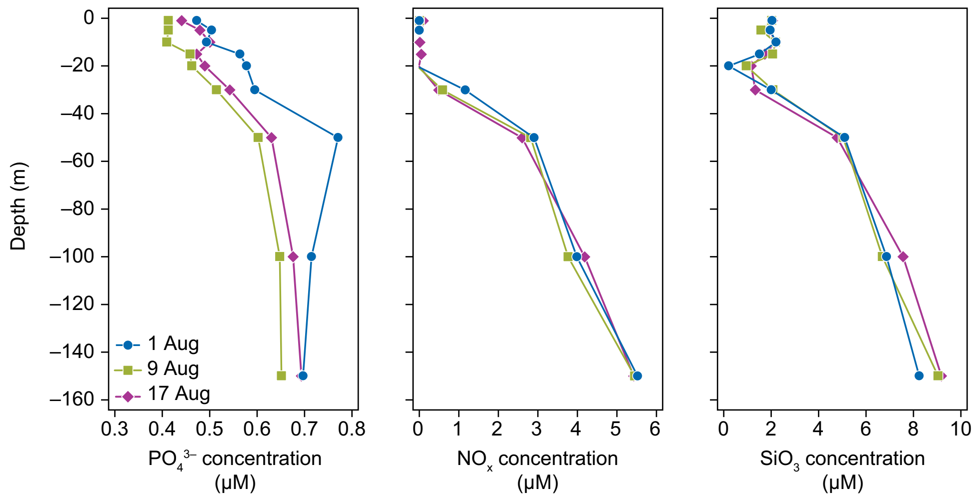
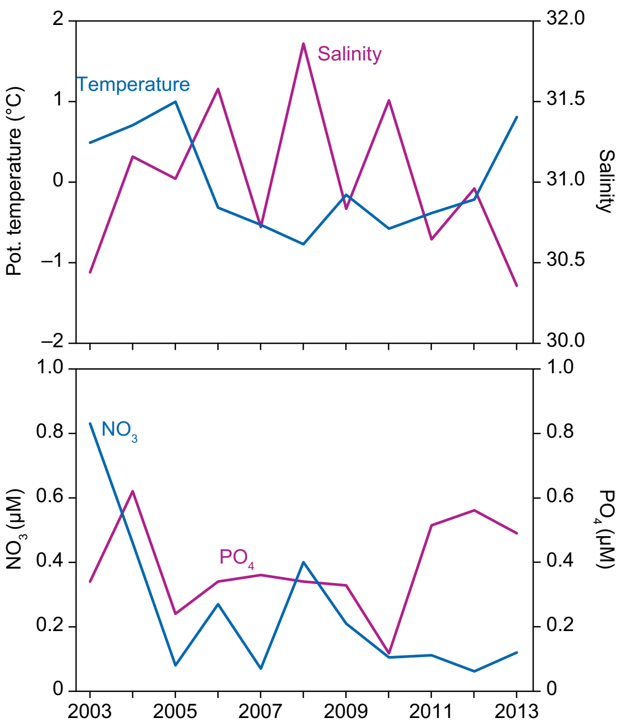


Figure 5.9 Vertical nutrient profiles at the 'Main Station' in outer Young Sund 2013.

is close to 29 ‰. The outflowing freshwater is more turbid and warmer than the inflowing water from the Greenland Sea. The sub surface peak in fluorescence is thicker below the outflowing freshwater. The other cross transect is near the sill at the entrance of the fjord (figure 5.7). In addition, here it is apparent that differences exist between the shores of the fjord and the high turbidity freshwater leaving the fjord visible near Clavering Island (right side of picture). At the 'Main Station' in the outer fjord vertical CTD profiles are measured as often as possible during the summer campaign to quantify short-term temporal variation (figure 5.8). During the three weeks in late July/early August the surface water gradually becomes warmer and salinity decreases. The sub-surface peak in fluorescence gradually disappears during the sampling period.

At the same station content of various nutrients is measured (figure 5.9). For NOx (nitrate + nitrite) the depletion of the upper 20 m is observed but with measurable concentration at 30 m. Phosphate is present in the surface water although concentrations are lower compared to below the photic zone. For silicate, there can be a significant input from terrestrial run-off and concentrations are therefore relative high near the surface and show a minimum at 20 m depth. Comparing the average conditions in the surface



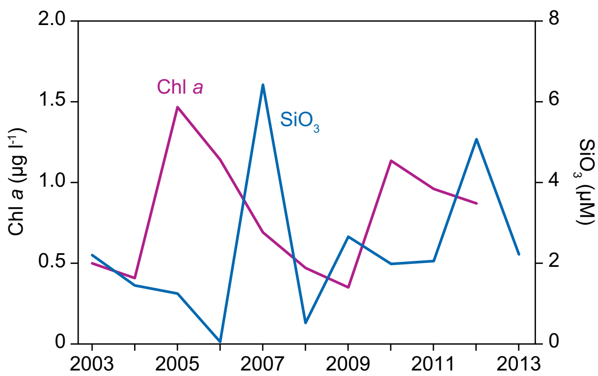


Figure 5.10 Summary of hydrographic conditions averaged over 0-45 m in August at the 'Main Station' in Young Sund.

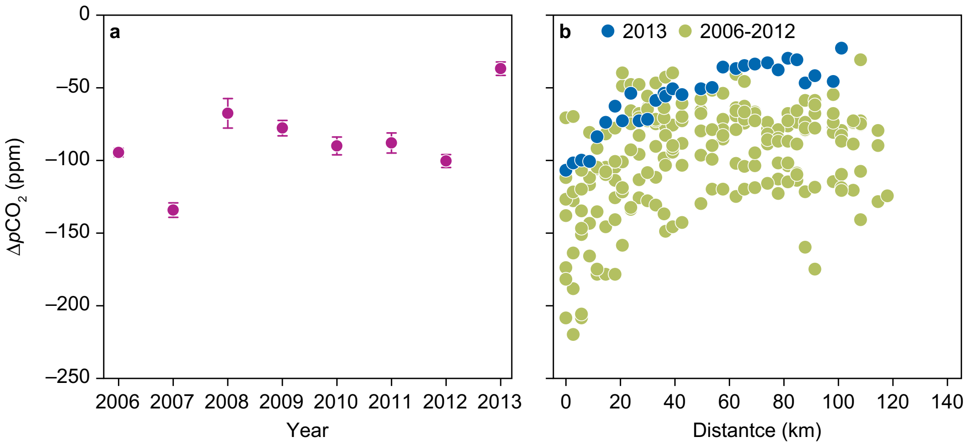


Figure 5.11 Difference in partial pressure of CO_2 (ΔpCO_2) between the atmosphere and surface water (1 m) in Young Sund. Left panel show average summer values (± se) for the 'Main Station' and right panel shows values along a transect starting in Tyrolerfjord and ending in the Greenland Sea. Negative ΔpCO_2 values indicate uptake of atmospheric CO_2 by the fjord.

layer (0-45 m) at the 'Main Station' with previous years (figure 5.10) 2013 is characterized by relatively high temperature and low salinity. Nutrient concentrations are high for phosphate, low for NOx and about average for silicate.

Surface pCO_2

The partial pressure of CO_2 (pCO_2) in the surface water determines the direction of the CO_2 exchange between atmosphere and ocean. By subtracting surface values with the CO_2 content in the atmosphere (close to 400) the resulting ΔpCO_2 will indicate whether the fjord takes up CO_2 from the atmosphere (negative ΔpCO_2 values). At the 'Main Station' (figure 5.11A), the average ΔpCO_2 showed the least amount of undersaturation measured since we started measuring this in 2006. When comparing with ΔpCO_2 measured along the fjord transect (figure 5.11B) it again shows that in the entire fjord ΔpCO_2 are less negative than average compared to what have been seen in previous years. A contributing factor to the lower undersaturation could be the early break up of sea ice in 2013. Usually when these measurements are conducted the fjord has been ice free between two to three weeks. This year the fjord had been ice free for five to six weeks which would have allowed increased time for uptake of atmospheric CO_2 resulting in increased surface water pCO_2.

Attenuation of light

The penetration of light into the water column is an important parameter for the distribution and production of phytoplankton in the fjord. Attenuation of photosynthetically available radiation (PAR) is measured along all transects and multiple times at the 'Main Station' (figure 5.12). In 2013, the average attenuation coefficient at the 'Main Station' was 0.14, which is close to the average of the sampling period.

Figure 5.12 Attenuation coefficients (average ± se) in the water column of photosynthetically available radiation (PAR) during summer (2003-2013).

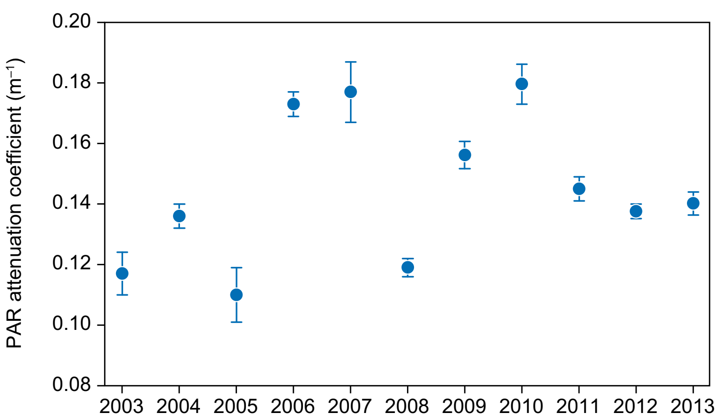


Table 5.2 Phytoplankton diversity in Young Sund at 0-50 m depth during 2013. The ten most abundant species are listed together with the relative proportion (%) of total cell count.

	1 Aug average	**9 Aug average**
No. Species	20.3	18.0
Shannon Wiener index	1.7	1.2
Pilous evenness	0.5	0.4
Chaetoceros cf socialis		65.2
Protoperidinium sp.		9.2
Chaetoceros decipiens		9.1
Dictyocha speculum		4.7
Fragilariopsis sp.		2.2
Thalassiosira sp.		1.6
Ciliata sp.		1.4
Synedropsis cf hyperborea		0.7
Parafavella denticulata		0.7
Mesodinium rubrum		0.5

Phytoplankton and zooplankton

The species composition of phytoplankton and zooplankton was quantified at the 'Main Station' on two occasions. The average number of taxa found was 20 and 18 (table 5.2). Diatoms were the dominant group and the *Chaetoceros cf socialis* was by far the most dominant taxa. The 10 most abundant taxa were similar to what have been found in previous years. Zooplankton species composition was also determined. The copepods (table 5.3) were dominated by different species belonging to the genus *Oithona* that constituted 68 % of all specimens. In previous year *Oithona* spp. has also been the dominant groups but only constituted about 30-50 % of the specimens found. The large Calanus species *C. glacialis, C. finmarchicus* and *C. hyperboreus* were found in lower numbers (absolute and relative) compared to previous years (figure 5.13A). The ratio between the arctic copepod *C. hyperboreus* and the more temperature *C. finmarchicus* has also changed significantly during the measuring period. In recent years the ratio has been close to one whereas the arctic *C. hyperboreus* was more dominant in 2003 and 2004 (figure 5.13B).

5.3 Sediment

Organic material transported to the seafloor may be degraded by oxidation within the upper oxic zone and by sulphate reduction below. Only a fraction of the organic material reaching the sediment is buried. Sediment cores are collected at a permanent sampling station (water depth approximately 60 m) and used for measuring exchange rate of solutes across the sediment-water interface. After recovery the sediment cores where incubated at *in situ* temperatures during the experiments in the laboratory. The total oxygen uptake (TOU) into the sediment (table 5.4) was low compared to the previous years (up to 6.624 mmol m^{-2} d^{-1} in 2008). The dissolved oxygen uptake (DOU) into the sediment is calculated based on oxygen profiles (figure 5.14) into the sediment and values were also in the low range of previous measurements at the same location (up to 6.323 mmol m^{-2} d^{-1} in 2005). The ratio of TOU to DOU is an indicator of bioturbation activity in the sediment, thus measurements suggests bioturbation comparable to previous years. The average oxygen

Table 5.3 Summary of the copepod species composition at the main sampling station in 2013.

		1 Aug (per m^{-2})		9 Aug (per m^{-2})	
		Average	se	Average	se
Calanus spp.	npl	3200.0	488.8	3029.3	368.6
	C I	48.0	16.0	69.3	28.5
	C II	106.7	45.6	160.0	88.4
	C III	122.7	19.2	106.7	17.3
	C IV	58.7	14.1	53.3	13.1
Calanus finmarchicus	C V	202.7	19.2	224.0	63.0
	female	44.0	4.6	26.7	3.3
	male	4.0	2.3	1.3	1.6
Calanus glacialis	C I				
	C II				
	C III				
	C IV				
	C V	245.3	78.6	149.3	47.1
	female	37.3	13.5	20.0	2.8
	male				
Calanus hyperboreus	C II	96.0	24.4	32.0	19.6
	C III	176.0	24.4	90.7	28.5
	C IV	181.3	21.3	245.3	34.6
	C V	36.0	6.1	5.3	1.6
	female	4.0	2.3	1.3	1.6
	male				
Microcalanus spp.	npl	74.7	10.7	74.7	34.6
Microcalanus pygmaeus	cop.	394.7	117.3	533.3	56.9
	female	5.3	5.3	64.0	22.6
	male				
Microcalanus pusillus	cop.	650.7	10.7	1898.7	158.9
	female	16.0	9.2	106.7	13.1
	male	0.0	0.0	32.0	11.3
Metridia longa	C I	21.3	14.1	74.7	23.6
	C II	10.7	5.3	42.7	23.6
	C III	26.7	19.2	74.7	6.5
	C IV	32.0	0.0	16.0	11.3
	C V	8.0	4.6	14.7	4.3
	female	9.3	4.8	30.7	7.1
	male	0.0	0.0	2.7	1.6
Oncaea borealis	npl	938.7	42.7	2218.7	317.9
	cop.	1248.0	129.3	469.3	26.1
	female	272.0	18.5	309.3	32.7
	male	874.7	21.3	650.7	202.8
Oncaea spp.	male				
Oithona similis	npl	26538.7	1089.5	12202.7	1831.2
	C I	330.7	10.7	554.7	104.5
	C II	3626.7	333.2	3541.3	408.1
	C III	2261.3	388.1	2816.0	627.1
	C IV	896.0	66.6	1322.7	113.9
	C V	917.3	105.1	1280.0	163.2
	female	1706.7	213.3	2880.0	497.8
	male	170.7	28.2	245.3	28.5
Oithona atlantica	female	0.0	0.0	1.3	1.6
Oithona	egg sacks	314.7	89.7	1664.0	394.5
Oithona spp.	female				
Pseudocalanus spp.	npl	4138.7	480.8	3541.3	209.0
	C I	661.3	74.7	586.7	128.7
	C II	1429.3	149.3	1600.0	0.0
	C III	629.3	139.9	917.3	265.2
	C IV	640.0	129.3	810.7	124.6
	C V	640.0	66.6	741.3	135.9
Pseudocalanus minutus	female	64.0	12.2	90.7	32.7
	male				
Pseudocalanus acuspes	female	136.0	30.3	245.3	6.5
	male	5.3	5.3	5.3	6.5
Pareuchaeta spp.	npl				
	C I				
	C II	1.3	1.3		
	C III			2.7	1.6
	C IV			1.3	1.6
	C V				

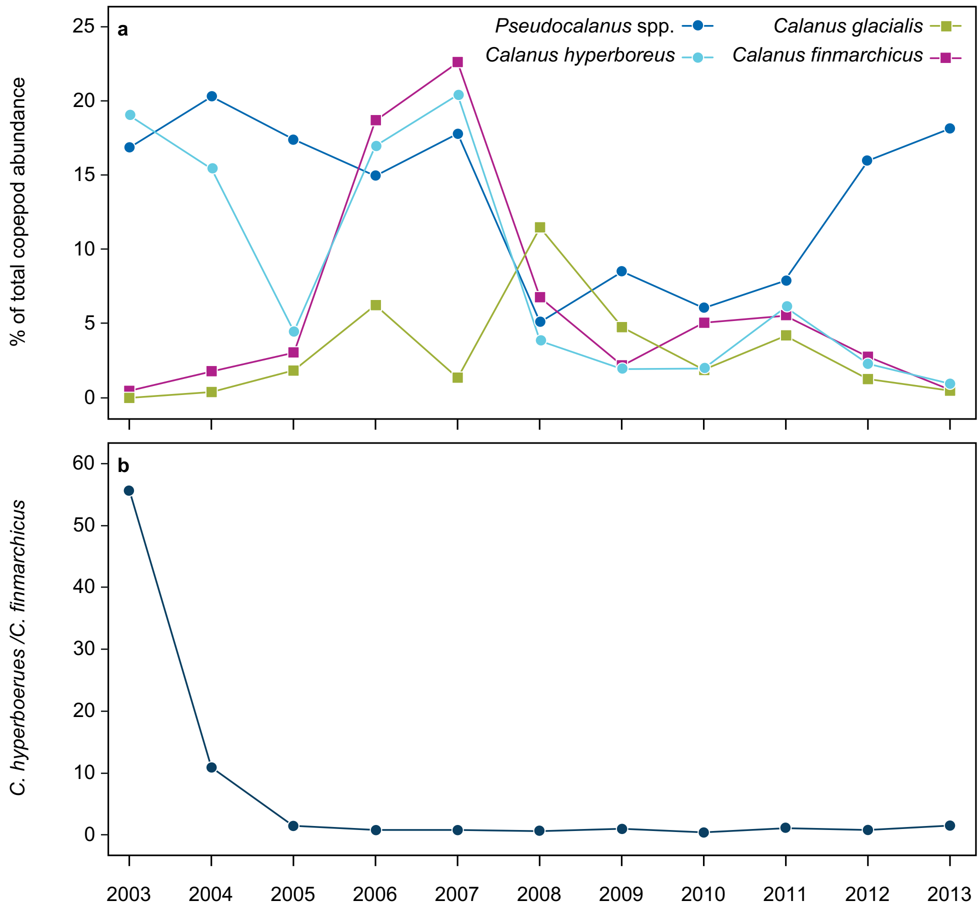


Figure 5.13 A) The relative abundance (%) of calanoid copepods found in vertical net hauls at the main sampling station 2003-2013. B. The ratio between the abundance of the arctic copepod Calanus hyperboreus *(adults and copepodits) and the temperate* Calanus finmarchicus *in Young Sund.*

Figure 5.14 Vertical concentration profiles of oxygen (dots) and modelled consumption rates (line) in the sediment at 60 m depth in Young Sund, August 2013.

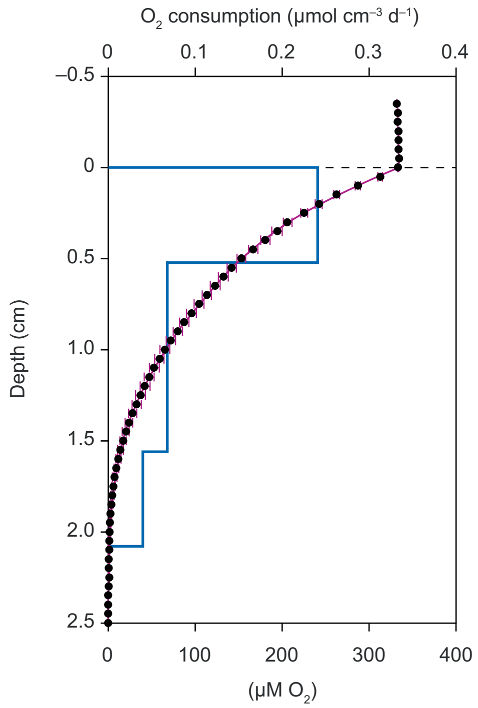


Table 5.4 Sediment-water exchange rates of O_2 (TOU), NO_3^- + NO_2^-, SiO_4 and PO_4^{3-} measured in intact sediment cores, diffusive oxygen uptake by the sediment (DOU) and the ratios of DOU to TOU and SRR to DIC flux. SRR/DIC flux is calculated in carbon-equivalents. n denotes the number of sediment cores. Positive values indicate a release from the sediment to the water column. All rates are in mmol m^{-2} d^{-1}. SE denotes the standard error of the mean.

Parameter	mmol m^{-2} d^{-1}
TOU	3.333
DIC	–
NO_3^- + NO_2^-	0.097
NH_4^+	–0.035
PO_4^{3-}	–0.003
SiO_4	0.766
SRR	–
DOU	1.902
TOU/DOU	1.753
SRR/DIC	–

penetration depth, i.e. the depth of the oxic zone, was 2.09 ± 0.06 cm (measured in nine sediment cores; data not shown), which is higher than in most previous years. Exchange rates of DIC were not analysed in time for the report due to instrumental problems, while sulphate reduction (SRR) was not measured during 2013.

Underwater plant growth

Large specimens of the brown algae *Saccharina latissima* are sampled in early August every year. In this species annual production of new blades can be identified and the length, biomass and production in terms of carbon can be estimated (figure 5.15).

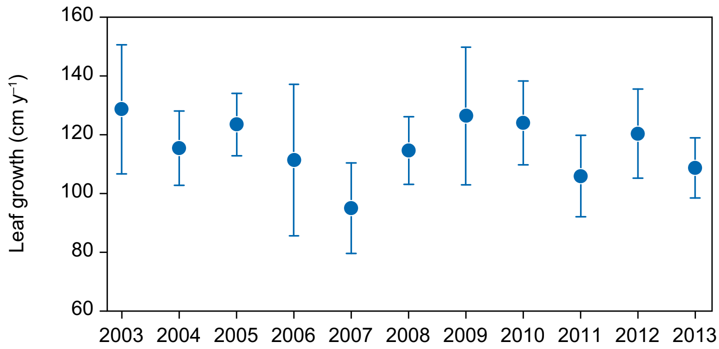


Figure 5.15 Average leaf growth (±SE) of the macroalgae Saccharina latissima *at 10 m depth in Young Sund.*

In 2013, the length of the new leave was 108 cm, which is near the average of the sampling period. Light availability is most likely the primary driver of annual growth in this species. Ice conditions are thus an important factor determining growth. Because the species is perennial the length of the leaf blade most likely integrates light condition during the year of collection and the previous years. Taking into account the early break up of sea ice in 2013 it is surprising that growth did not exceed average. The annual growth is also estimated in carbon units but that analysis has not been completed yet but will be presented in next year's report.

6 Research projects

6.1 Mass and energy balance monitoring on Freya Glacier

Bernhard Hynek, Daniel Binder, Gernot Weyss and Wolfgang Schöner

Since the International Polar Year (IPY) in 2007/08 the surface mass balance of Freya Glacier on Clavering Island has been measured using the direct glaciological method.

There have been two field trips to the glacier in 2013. On 5 May 2013, Daniel Binder and Geo Boffi maintained the automatic weather station (AWS) on the glacier (figure 6.1), installed two automatic cameras for snow cover monitoring and carried out distributed snow height measurements on the glacier (Hynek and Binder 2013). Due to a persistent snow drought over a large area of East Greenland in winter 2012/2013, snow height in

Figure 6.1 The automatic weather station (AWS, 860 m a.s.l.) on Freya Glacier during the spring survey (5 May 2013, snow height ~70 cm) and at the end of summer (14 August 2013) after an ice loss of 80 cm. Photos: Geo Boffi and Bernhard Hynek.

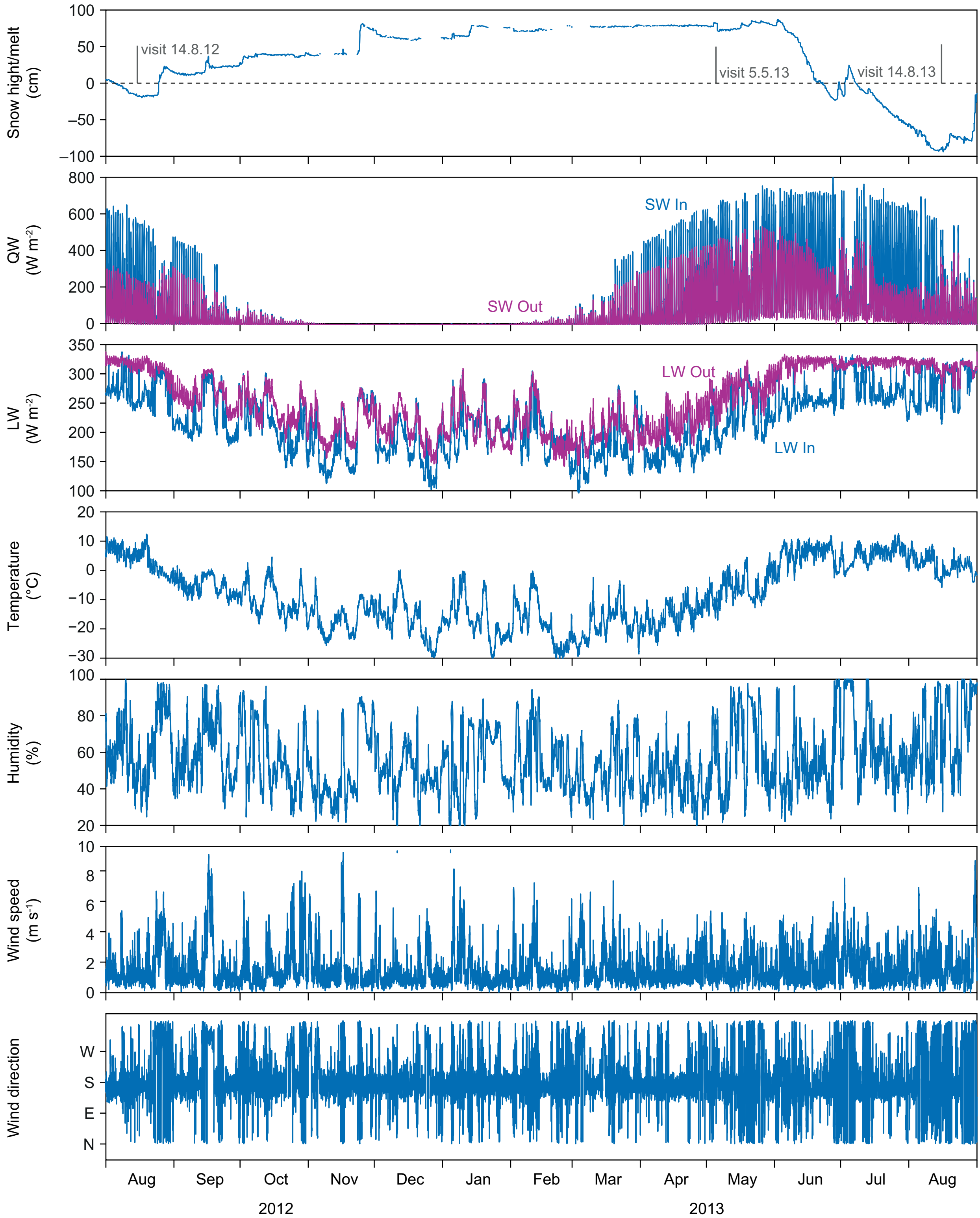


Figure 6.2 Data from the automatic weather station (AWS, 860 m a.s.l.) on Freya Glacier from August 2012 to August 2013.

the Zackenberg region was extremely low compared to previous years, which inhibited snow scooter travel to the glacier, so the Freya glacier could only be reached by foot. Based on 28 snow height probings along an altitudinal profile the mean snow height on the glacier was only 50 cm, which is extremely low compared to previous surveys in 2008 and 2012 with a mean snow height of 180 cm and 250 cm, respectively.

Field work at the end of the melt season was carried out by Daniel Binder and Bernhard Hynek 10-18 August 2013 (Hynek 2013a). Within that field trip, surface mass balance was measured at 16 locations on the glacier, data from the automatic stations was collected (figure

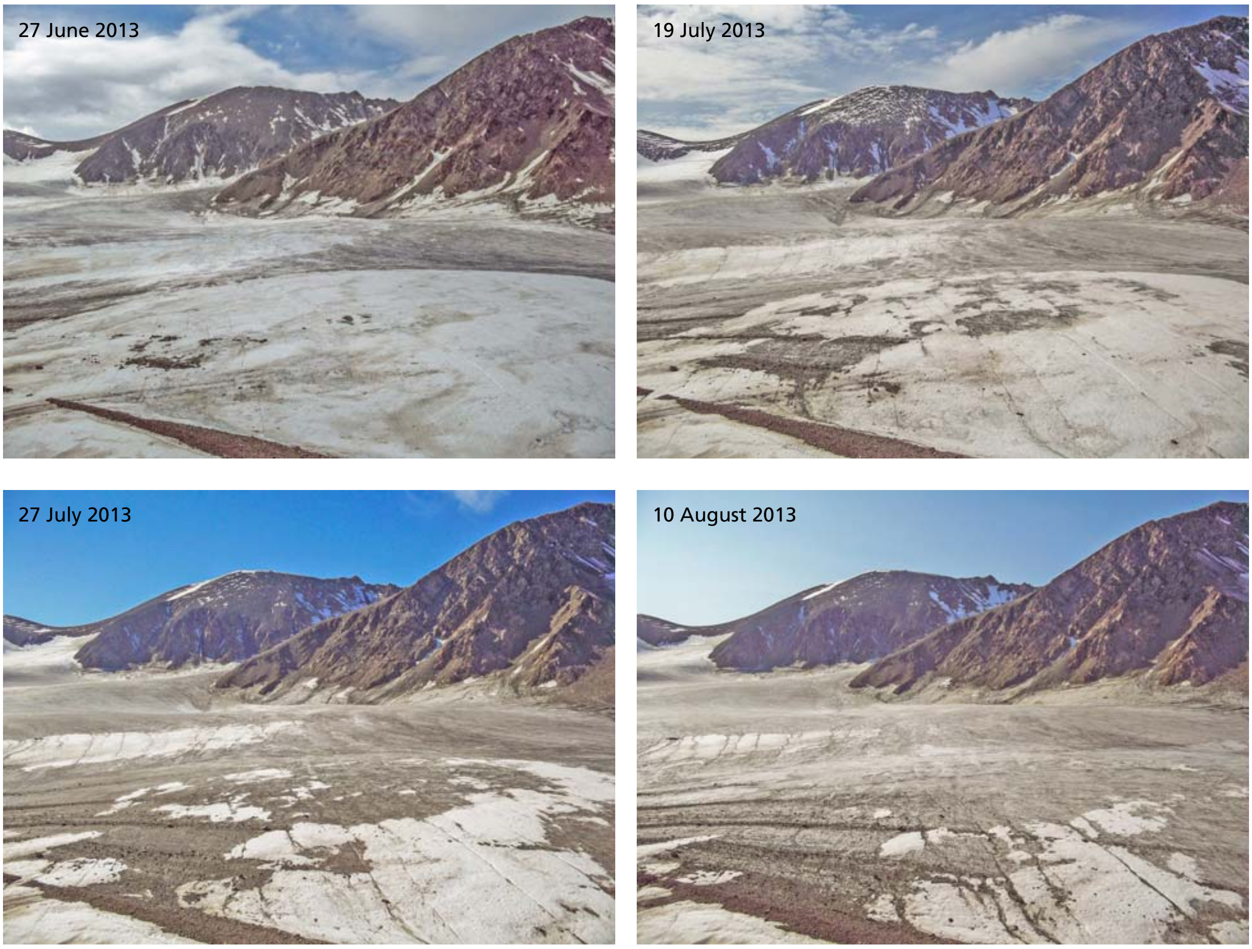


Figure 6.3 Photos from the upper automatic camera on Freya Glacier demonstrate the early snowmelt in summer 2013 even at high elevations and the very slow retreat of some remaining snow patches, where the snow cover had previously been densified by refreezing processes.

6.2) and a photogrammetric and Global Navigation Satelite System (GNSS) survey of the glacier surface was carried out (see section 6.2).

The low winter accumulation led to a very early melt of the snow cover. Figure 6.3 shows, that the snow cover already had disappeared on large areas even at high elevations by the end of June for a time lapse movie of both cameras (see Hynek 2013b). The early melt of the snow cover resulted in a long exposition of the bare ice surface throughout the summer and extreme high mass losses in 2012/2013. While a negative annual mass balance was observed on 97% of the glacier area with the highest ice thickness loss of more than 3 m, the area averaged mass balance was –1.4 m water equivalent, which is more than twice as high as in previous years.

Based on the photogrammetric survey of the glacier during August 2013 (Hynek et al. 2014a) all mass balance point measurements of Freya Glacier from 2008 to 2013 have been evaluated on the actual glacier area and on elevation bands derived from the digital elevation model of 2013. All mass balance data of Freya Glacier are published in the Pangaea database (Hynek et al. 2014b). These datasets will be updated annually.

6.2 Straightforward surface reconstruction with a camera: A new DEM of Freya Glacier

Bernhard Hynek, Geert Verhoeven, Daniel Binder, Geo Boffi and Wolfgang Schöner

Terrestrial photogrammetry was the standard method for mapping high mountain terrain in the early days of mountain cartography, until it was replaced by aerial photogrammetry and LIDAR. Modern low-price digital single-lens reflex (DSLR) cameras and highly automatic and cost-efficient digital computer vision software with image matching and multiview-stereo-routines (MVS) suggest a rebirth of terrestrial photogrammetry, especially in remote regions, where airborne surveying methods are expensive due to high flight

Figure 6.4 Panoramic photo of Freya Glacier taken during the photogrammetric survey of the upper part of the glacier 12 August 2013. Photo: Bernhard Hynek.

costs. Terrestrial photogrammetry and modern automated image matching is widely used in geodesy (e.g. James and Robson 2012), however, its application in glaciology is still rare (e.g. Winkler et al. 2012), especially for surveying ice bodies at the scale of some square kilometres, which is typical for Alpine valley glaciers. Image acquisition of larger glacier areas is usually done by unmanned aerial vehicles (UAVs, e.g. Immerzeel et al. 2014).

In this study we applied structure-from-motion (sfm) and multiview stereo (MVS) algorithms to derive a digital elevation model (DEM) and an ortho-mosaic from oblique and unsorted terrestrial imagery of Freya Glacier, a 5.3 km² large valley glacier on Clavering Island.

The photogrammetric and GNSS measurements have been carried out on three days by two persons during glacier mass balance fieldwork in August 2013. During the survey of the upper part of the glacier 11 and 12 August the glacier surface was almost totally snow free (see figure 6.4). After some days of bad visibility and snowfall the lower part of the glacier was surveyed 18 August, when the glacier surface was covered by 5-20 cm snow. Due to persistent bad weather the fieldwork had to be ceased early, so the mid-part is not as densely covered by photos as the rest of the glacier. In total about 900 photos were taken from the ridges surrounding the glacier with a Nikon D7100 DSLR camera and a 20 mm fixed zoom lens. Parallel to the image acquisition 98 visible ground control points (GCPs, see figure 6.5) were measured using differential GNSS.

The accuracy and resolution of structure-from-motion photogrammetry is above all limited by the measurement geometry. If image acquisition is carried out by low altitude flying UAVs, results are typically better than those obtained by airborne LIDAR. In this study, the typical image distance was 600 m and the typical angle

Figure 6.5 GNSS-base station and GNSS survey of ground control and tie points to georeference the photogrammetric model. Photos: Bernhard Hynek.

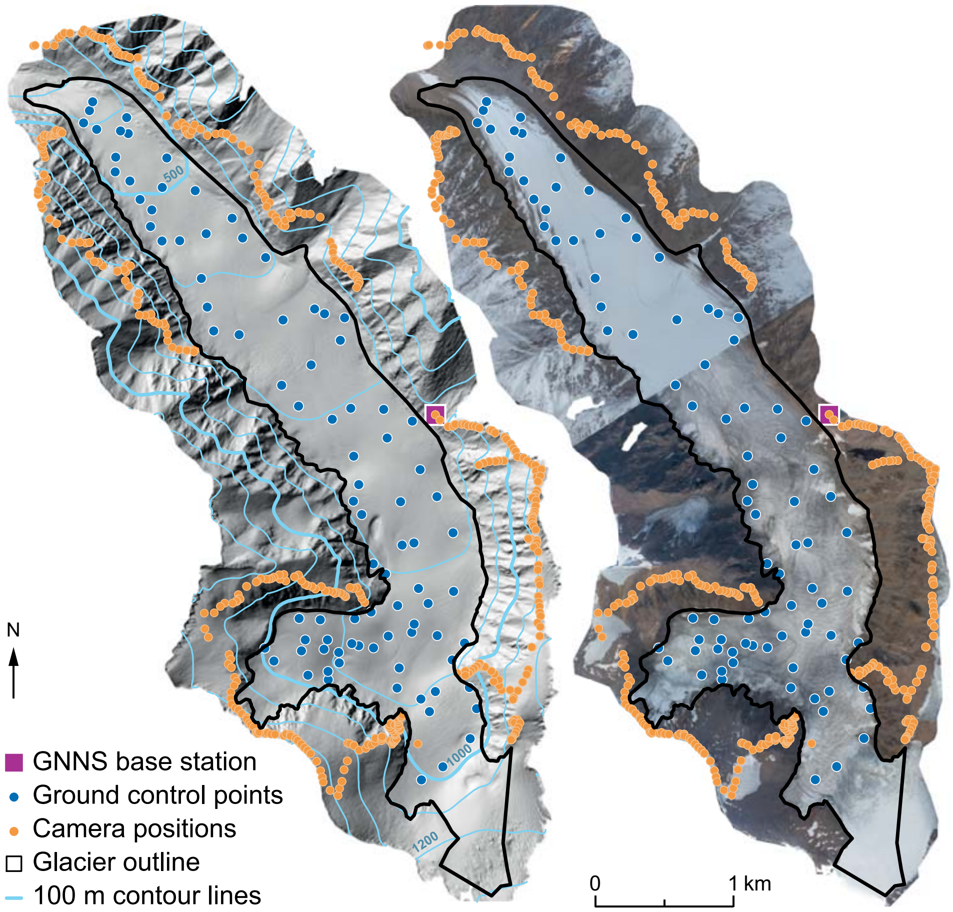
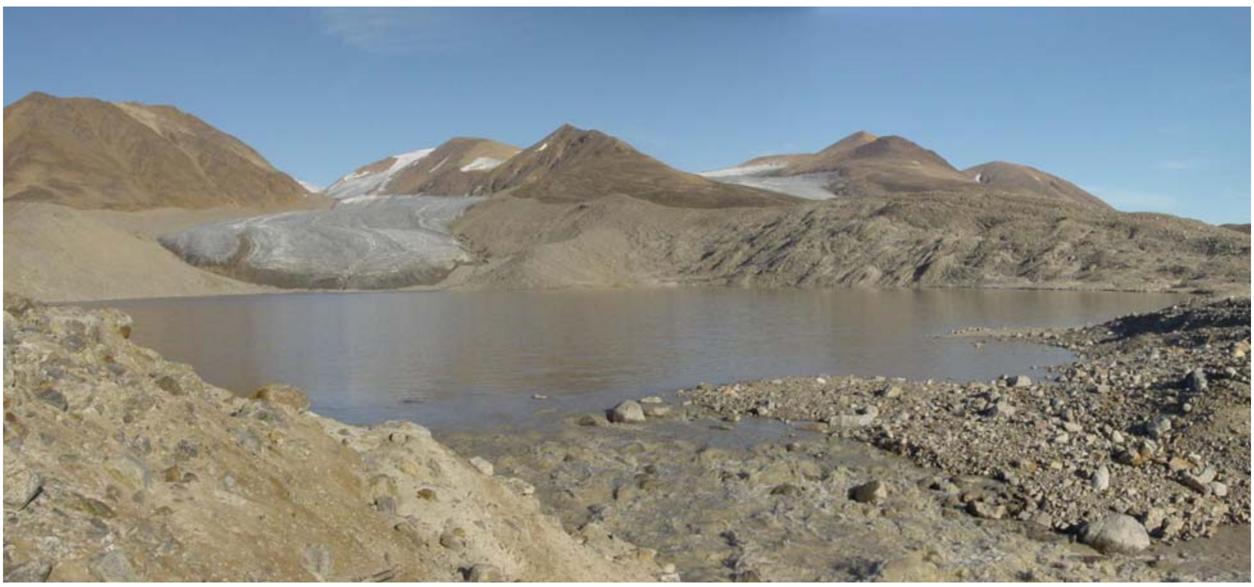


Figure 6.6 Maps of Freya Glacier of August 2013 with the location of the camera positions and the ground control points. The hill shade (left) and the ortho-mosaic (right) are derived from the terrestrial imagery by sfm-MVS algorithms.

to the glacier surface was only around 20 degrees (see figure 6.6 for an overview of the survey geometry). The mean positional accuracy of the generated 3D-model for all ground control points is 0.25 m, and the resolution of the generated DEM is 1 m (Hynek et al. 2014). These results come very close to those obtained by airborne LIDAR (Joerg et al. 2012). Given the low equipment costs, the ease of use and the highly automatized sfm-MVS software packages, this is an extremely cost efficient method to derive high resolution topographic data on a regular basis, which is of high interest in environmental monitoring.

Fieldwork for this research project was funded by the Austrian Society of Polar Research.

Figure 6.7 Moraine-dammed lake on Clavering Island. Photo: Vincent Rinterknecht.



6.3 Dating the retreat of the ice caps around Zackenberg using cosmogenic Be-10 in rocks

Vincent Rinterknecht and Vincent Jomelli

The DATECH2 (Dating Techniques 2) project is building on the successful field campaigns of 2011 and 2012 and was funded by INTERACT. Over the past two field seasons we investigated sites near Sermilik (eastern Greenland), near the Arctic Station on Disko (western Greenland), and south of Narsarsuak (southern Greenland). In 2013, we completed our network of cross-calibration sites to build a complete data set around Greenland. To this we have selected three sites near Zackenberg (74°36′49″N 21°21′16″W; 74°34′01″N 21°32′27″W; 74°36′49″N 22°08′11″W) (figure 6.7). The project is centred on the recent (in the last 400 years) fluctuations of satelite ice caps west of Zackenberg. All together, the full network of sites have been chosen to identify possible a/synchrony between the different regions investigated around Greenland.

The outcomes of the project are: 1) to build a strong and detailed chronology of the ice margin fluctuation to better understand the dynamics of the ice margin during the Little Ice Age, 2) to provide new local production rates for the Be-10 surface exposure dating technique, and 3) to identify any a/synchrony around the coast of Greenland that may be linked to shifts of major climatic systems affecting various regions of Greenland at the time.

The timeframe we are interested in, the last ~400 years, is of special interest to capture the recent changes in the cryosphere. Direct chronologies (e.g. cosmogenic nuclides) from this time period are particularly needed to improve the performance of the models to understand underlying mechanisms of climate change (e.g. paleo NAO-like climate footprints around the North Atlantic region). Our first results from the Sermilik site suggest that the sequence of moraines we sampled (five moraines) were indeed deposited between 200 ^{10}Be year and 1,500 ^{10}Be year. This provides us with good confidence that the sequence of moraines we identified and sampled near Zackenberg are datable with our palette of dating techniques. In any events, we will be able to date the moraines by cosmogenic Be-10, would the moraines be older than 1000 years (figure 6.8).

Figure 6.8 Rock sample ZAC-43 for surface exposure dating using cosmogenic Be-10. Photo: Vincent Rinterknecht.

The 45 rock samples collected around Zackenberg and on Clavering Island are currently processed and analysed at the French AMS facility. The detail list of sampling positions was registered with BioBasis Zackenberg and series of pictures of the visited sites where left to the GeoBasis Zackenberg to share with other projects.

6.4 Comparing periglacial landscapes and permafrost conditions of NE Greenland to Svalbard

Hanne H. Christiansen, Bo Elberling, Mette Bendixen, Wesley R. Farnsworth, Graham L. Gilbert, Kjersti Gisnås, Stefanie Härtel, Cecilie S. Nielsen, Juri Palmtag, Suvi M. Saarnio, Niels Weiss and Andreas Westergaard-Nielsen

During two and a half weeks the University Centre in Svalbard (UNIS) Ph.D. field course AG-833 *High Arctic Permafrost landscape dynamics in Svalbard and Greenland* studied Arctic periglacial geomorphology and permafrost conditions in northeast Greenland based at the Zackenberg research station in late summer 2013. The course was led by Hanne H. Christiansen and Bo Elberling both from UNIS and the Centre for Permafrost (CENPERM), University of Copenhagen. The course was

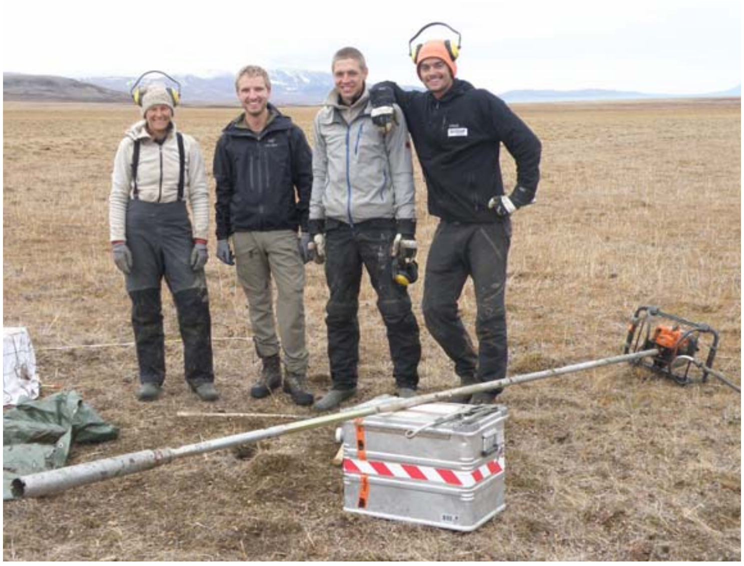


Figure 6.9 Happy students about to set the record in hand drilling down 4.7 m into the permafrost in a large nival alluvial fan in the Zackenberg lowlands. The entire drill string seen in the foreground. From left to right Stephanie Härtel, Graham Gilbert, Niels Weiss and Wesley Farnsworth 26 August. Photo: Hanne H. Christiansen.

Figure 6.10 Lecturers and students in front of Dombjerg at Zackenberg 4 September. Photo: Art Koon.

primarily funded by the Nordic Council's collaboration programme called Perma-Nordnet, which focus on networking on permafrost research and education in the Nordic area. UNIS and CENPERM also partially supported the course enabling this special course to run as one of three specialized Ph.D. courses in Perma-Nordnet. The ten course participants came from the Universities of Copenhagen, Stockholm, Oulu, Oslo and UNIS (figure 6.9).

The course focused on field methods such as geomorphological mapping, retrieval and analysis of permafrost cores and studies of natural sections. Sites were selected to represent the different periglacial landforms of the Zackenberg landscape ranging from long solifluction slopes to large deltas. A visit to the more continental landscape in the inner part of the fjord system at Revet close to the Greenland Ice Sheet set the course in perspective with respect to also local climatic gradients and their influence on the landscape development, just as we experienced the former traditional way of trapping that this landscape was used for by both Danes and Norwegians (figure 6.10).

A first overview of the 28 m of hand drilled permafrost cores was obtained during the course, but further studies have been carried out to gain a detailed understanding of the sedimentary stratigraphy, age, as well as ice and carbon content. By combining these different methods it is possible to develop a better understanding of past climatic conditions in NE Greenland, as well as to interpret how the landscapes will respond to future climate conditions. In addition, course participants will use existing climate and cryostratigraphic data to compare the Svalbard region to northeast Greenland. Despite the relatively close geographic proximity these two regions are at opposing ends of the steepest climatic gradient in the Arctic. Analysis of ground temperature data from boreholes instrumented in summer 2012, and now downloaded for the first time in summer 2013 during this course, will provide the first snapshot of the permafrost thermal regime in NE Greenland, and allow for comparison directly with the Svalbard permafrost temperatures.

Two final course reports have been submitted in end of January 2014, graded and a final course workshop with presentation of all data was held at CENPERM at University of Copenhagen in February 2014 as part of a Perma-Nordnet workshop.

6.5 Impact of permafrost on the stability of sedimentary shores in the Young Sund area

Aart Kroon and Mette Bendixen

Coastal environments in the Arctic will change in the near future due to climate change. The presence of sea-ice and per-

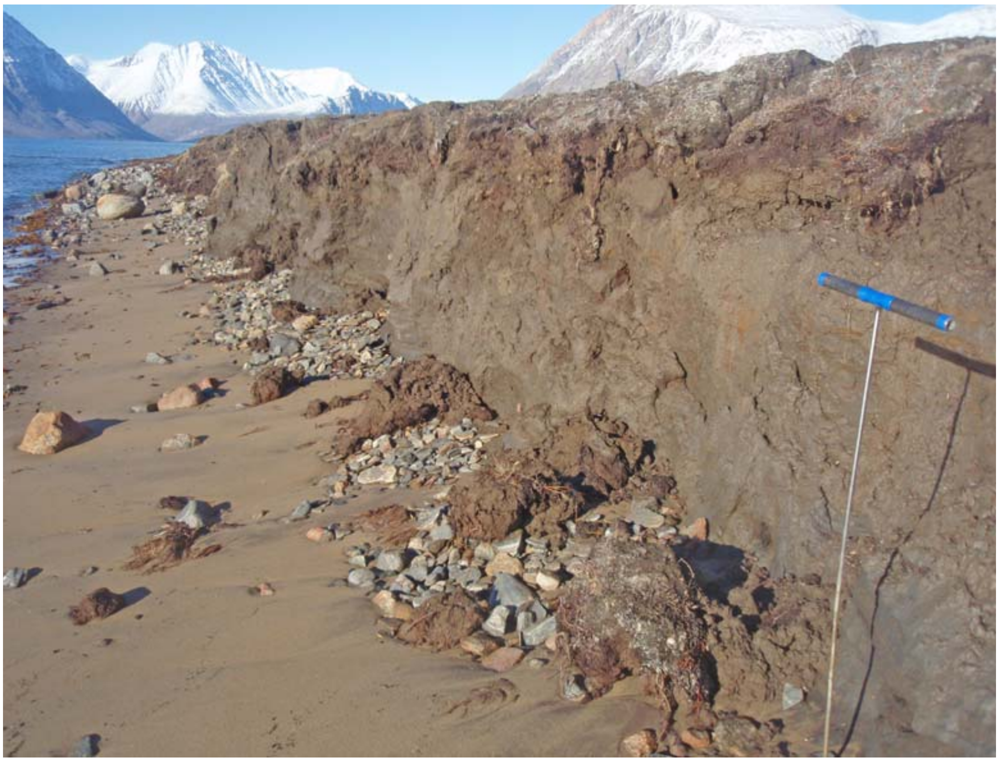


Figure 6.11 A profile of an eroding cliff at the eastern end of the old Zackenberg delta 5 September 2013. The stick of 1.5 m is used to measure the active layer thickness. Photo: Art Koon.

mafrost will be reduced due to an increase of local air and seawater temperatures. Wave-driven coastal processes on shorelines will become more prominent due to an extension of the ice-free seasons. This will increase the erosion of cliffs and beaches along the shores. At the same time, the exposure of the eroding cliffs will locally enhance the thawing of the permafrost in the cliff. This reduces the strength of the cliffs in sedimentary environments. This project is focused on an analysis of present day coastal changes and more in detail on the strength of the coastal cliffs in the Young Sund area, close to the Zackenberg delta.

A satellite image of 2012 was used to map the coastal geomorphology of the Young Sund area around the Zackenberg delta. The dynamic behaviour of the Zackenberg delta with the formation of spits in front of the old delta lobe and erosion of cliffs further off the present river distributary or close to the riverbed, was quantified by comparing the shorelines on successive aerial photos and satellite images from 1932 to 2012 (see also Kroon et al. 2011). The morphological map and the computed migration rates of the present day shorelines helped us to select specific eroding cliffs.

Field work was carried out at the end of the summer along coastal cliffs

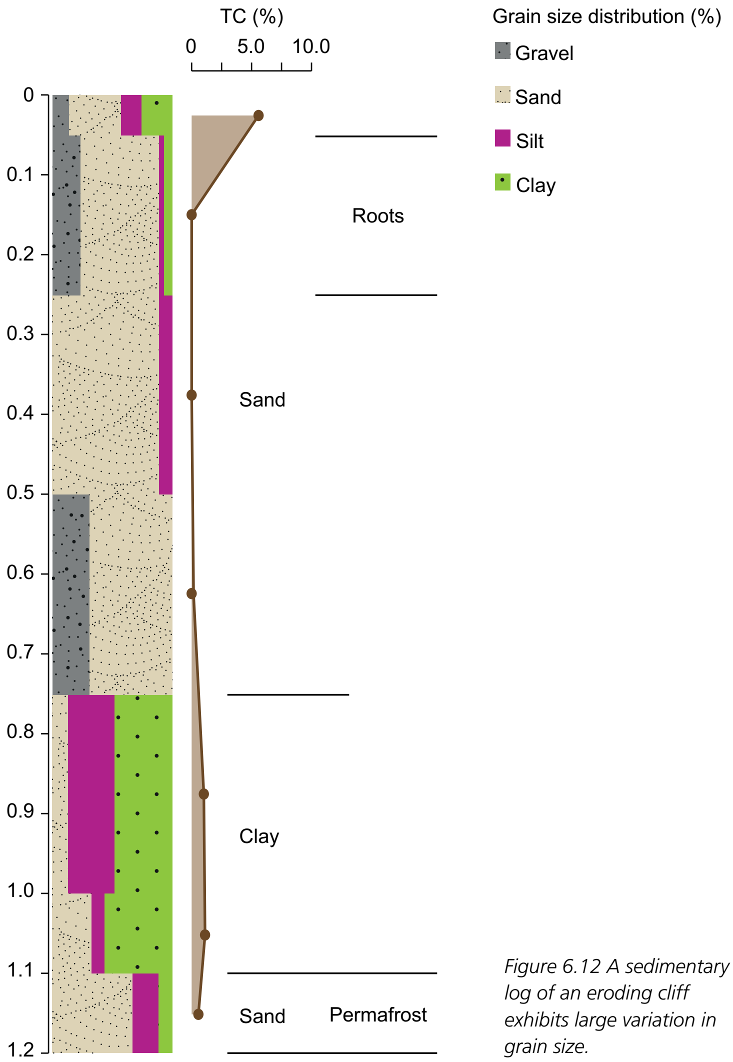


Figure 6.12 A sedimentary log of an eroding cliff exhibits large variation in grain size.

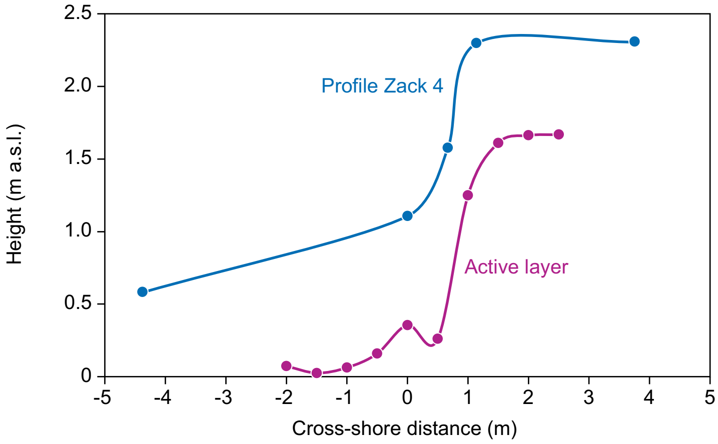


Figure 6.13 The active layer depths range from 0.63 cm – 0.92 cm, with the lowest depths around the toe of the cliff.

in sedimentary environments. Most of these sedimentary cliffs were built up by Holocene marine deposits of former deltas and all cliffs were facing to the south. At nine locations, we looked in detail to the vertical profiles (figure 6.11). We measured the topography with an RTK-DGPs system and sampled the sedimentary characteristics, like grain sizes, organic carbon content, in the profile; we also determined the active layer thickness on top of the permafrost over the topographic profile using a steel probe and applied a horizontal spacing of 50 cm between observations. Figure 6.12 shows an example of the cliff topography and its active layer at the end of the season (early September observations). Most of the time, the active layer followed the topography, but the active layer is smallest near the toe of the cliff (figure 6.13).

At Cape Berghaus at the mouth of Young Sund, we even observed that the permafrost was exposed at the toe of the cliff after an erosive wave event on the previous day. The exposure of ice on the beach reduced the erodibility of the cliff and protected the shore from further erosion. The large variation in grain size is caused by the dynamic nature of the former delta outlet; during periods where the outlet was located far away from the shown site, fine particles were deposited. When the outlet was located at a close proximity, coarser material was deposited. As the delta outlet naturally shifts its orientation, the deposited material will therefore consist of a mix of grain sizes. The organic content is rather low, but increases with the presence of finer material.

6.6 Epi- and endolitic micro-colonial fungi in high Arctic environment (the Zackenberg valley, North-East Greenland)

Katja Sterflinger, Andreas Noack, Natasa Saric and Christian Voitl

The Arctic is defined as the land or sea north of the Arctic Circle, where there is midnight sun in the summer and winter darkness, it is the land north of the tree line which generally has a mean temperature below +10-12 °C in the warmest month (July) (Jonasson et al. 2000). Whereas the diversity of microcolonial fungi was studied extensively in the Antarctic environments and in many mountain regions of the world (Selbmann et al. 2005), data on rock inhabiting fungi of the Arctic are still missing. This is the first survey of fungi isolated in the high Arctic environment, including samples from Greenland at 74 °N.

Material and methods

Sampling site: Sampling was carried out 3-17 July 2013 during a stay at Zackenberg research station. A list of the total of 22 rock samples is given in table 6.1.
Sampling: Sampling was carried out using a geological hammer, samples were transferred into sterile bags (Nasco, whirl pack), carried to the Zackenberg station and air dried at 15-17 °C in the Zackenberg laboratory. Air dried samples were stored in sterile bags until transport at 4 °C.
Isolation of fungi: Fungi were isolated from the rocks by picking single colonies with surgical needles and transferring them directly onto different media (DRBC, MEA) thereby using a dissecting microscope. Plates are checked daily and fast growing contaminants are immediately removed from the plates by cutting the agar out. Plates are incubated at room temperature and at 15 °C respectively for up to four weeks. Colonies of black fungi are transferred onto fresh plates of 2 % MEA.
Identification of fungi: Fungi will be identified based on sequencing the ITSI-5.8-S-ITSII and SSU region of the genome.

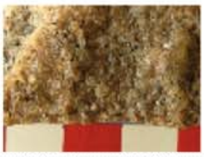
Results and discussion – Preliminary

Astonishingly, although it is strikingly obvious that lichen, micro colonial fungi (MCF) and cyanobacteria are covering most of the rock surfaces, dominating not only the optical appearance of the stone but also contributing significantly to the weathering of the rocks and being physiologically active, data quantifying the CO_2 uptake and/ or release by this biocrusts are missing. The terrestrial surfaces covered with active biocrusts are extensive – even endless in a fractal dimension – and the gas fluxed might have an impact on global process connected to climate change. After the first survey of fungal isolates from the Zackenberg valley we see a diversity of up to 20 different species of microcolonial fungi. The diversity resembles the diversity found in Svalbard (Ny Ålesund area, Sterflinger, unpublished data) and the fungal community is mainly composed of mesophilic black fungi; real extremophiles – as found in the Antarctic environment – are missing. The final identification of the fungi based on DNA sequencing data is still in progress.

Table 6.1 Rock samples from the area around Zackenberg Bay. Photo: Katja Sterflinger.

Sample no./date	Description / rock type	GPS position/UTM	Biology
ZA 1 6 July 2013	Grey with salmon, very dense, (possibly gneiss)  	N 74° 30`21.0`` W 20° 35`0.1`` 80 m	*Umbilicaria, Xanthoria, Rhizocarpon*, yellow/green crust lichen, casmoendolithic cyanobacteria, few MCF colonies on small parts of the sample  
ZA 2 6 July 2013	White to light grey, quartzitic/granitic 	N 74° 30`16.1`` W 20° 34`48.4`` 78 m	Some *Xanthoria*, and Rhizocarpon, chasmoendolitic cyanobacteria, full of black mycelium and small colonies of MCF at crystal boundaries  
ZA 3 6 July 2013	Dark sand color, interior rust colored (iron oxide) with glimmer, very dense, possibly basaltic  	N 74° 30`12.8`` W 20° 34`35.1`` 83 m	Black lichen crusts, full of small black MCF colonies in the quartz particles 
ZA 4 8 July 2013	Sandstone, light ocker  	Østerport N 74° 29`19`` W 20° 34`24. 5`` 39 m	Black between crystals, full of black biomass, fungi and possibly lichen material 
ZA 5 8 July 2013	Sandstone like ZA 4  	Østerport Moraine	Black between crystals, full of fungi (MCF) between crystals, especially in zones where the rock is stained yellowish 
ZA 6 8 July 2013	Dense rock, reddish like rust, no crystals, weathered shales 	Østerport Next to ZA 4 	Densely covered with *Umbilicaria* sp. and with black and grey crustous lichen, some fungal colonies 

ZA 7 8 July 2013	Crystalline, posslibly quartz/granite  	Østerport Moraine	Dense black lichen crust, endolitic cyanobacteria, no visible fungi	
ZA 8 8 July 2013	Dense reddish sandstone  	Østerport N 74° 29`21. 9`` W 20° 34`24.9``	Lichen crust, some fungal colonies in the more corroded part	
ZA 9 8 July 2013	Light ocker to grey, granite (granite?) 	Østerport 	Lichen crust, some fungi possibly under the *Umbilicaria*	
ZA 10 8 Juli 2013	Mixed rock, sample taken from white crystalline part 	Østerport 	Lichens and cyanobacteria (in cracks); fungal colonies (MCF) between crystals	
ZA 11	Light grey crystalline like quartzite or granite? 	Østerport 	Lichen crusts but also uncolonized surface, fungal colonies between crystals	
ZA 12 8 July 2013	Monolithic rock with big quartz crystals on top 	Østerport 	Lichens and many cyanobactera inside, plenty of fungal colonies at grain borders	
ZA 13 9 July 2013	Basaltic columns 	N74° 31`24.8`` W 20° 28´29.4´´ 628 m Top of Aucellabjerg 	Lacks any signs of biology, no lichen, no cyanobacteria visible, if there are fungi they cannot be distinguished from the black particles of the basalt	
ZA 14 9 July 2013	Basalt from the field down from 13 	Slopes of Aucellabjerg 350 m 	More blackish on the surface than the basalt up, but only very few lichens, no fungi visible	

ZA 15	Reddish, dense rock but differs from the basalt 	Slopes of Aucellabjerg 200 m	Lichens, if there are fungi they cannot be distinguished from the black particles in the rock 
ZA 16 9 July 2013	Salmon to white crystalline, quartzitic 	Slopes of Aucellabjerg 200 m 	Rhizocarpon, black crustous lichen and MCF between crystals 
ZA 17 9 July 2013	Crumbling (possibly carbonatic) material as outer "shale" of a more crystalline rock 	Slopes of Aucellabjerg 150 m 	Lichens, mainly *Xanthoria*, densly, no visible fungal colonies, some reddish-brown may be fungi 
ZA 18 11 July 2013	Light beige to salmon (quartzite) 	Østerport 	With black lichens and MCF in cracks and between crystals 
ZA 19 11 July 2013	Fine grained quartz, light white to grey, sandstone 	Østerport Moraine 	Plenty of MCF under the surface 
ZA 20 11 July 2013	"Iron shale" exfoliationg from rusty block 	Østerport Moraine 	No lichen, nor MCF 
ZA 21 11 July 2013	Light ocker-grey quartzitic sandstone 	Østerport Moraine 	Grey lichen crust, MCF under surface between crystals 
ZA 22 11 July 2013	Salmon to peach colored fine grained stone / sandstone	Østerport Moraine	Nearly exclusively *Umbilicaria* sp. 

6.7 MICROTEA: Structure and function of microbial communities in challenging, polar terrestrial habitats: A pan-Arctic survey

Stefano Ventura, Katja Sterflinger, Ondrej Komarek, Luigi D'Acqui and Roberto De Philippis

The visit to Zackenberg has been part of an INTERACT-sponsored, pan-Arctic survey of Biological Soil Crusts (BSC), lithobiotic microbial communities, and cyanobacterial communities of springs and seepages. Looking for patterns of distribution and variation of such structures around the Arctic, we hypothesised that water represents the key factor controlling their development; that they are composed by a restricted number of well adapted microbial species all over the Arctic; that they possess common patterns of development and biodiversity through the Arctic; and that Arctic communities, though less isolated than the corresponding communities in the Antarctica, are nevertheless largely autochthonous.

Objectives: The objectives of the research were to investigate the micro structure and the related hydrodynamic properties, the community composition, and the development pattern of BSC; identify and characterize the dominating members of fungal and cyanobacterial populations colonising exposed rock surfaces in different microclimatic conditions in the Arctic region; and finally to identify community members of mats in seepages and springs and characterize their photosynthetic behaviour.

On site work: We collected and stabilised samples to be further analysed at home. Cyanobacterial mats were collected for identification of their components, and their sensitivity to light and temperature measured via Chl *a* fluorescence method in the station laboratory. The work at Zackenberg research station has been planned and executed as a step of a pan-Arctic survey and all collected samples will be analysed in a comparative approach with samples previously collected in the other studied locations around the Arctic.

The field work mainly consisted of collecting samples from the variety of terrestrial habitats easily accessible within a

Figure 6.14 Mature Biological Soil Crust from the moraine hills in the centre of the valley. Unit = 1 cm. Photo: Stefano Ventura.

Figure 6.15 Laminar cyanobacterial macrocolony of Nostoc *cf.* commune *sitting on wet soil on the Aucellabjerg slope. Unit = 1 cm. Photo: Stefano Ventura.*

Figure 6.16 Endolithic microbial community. Unit = 1 cm. Photo: Stefano Ventura.

one day reach from the station. Habitats sampled for BSC included slopes on the side of moraine hills in the centre of the valley (figure 6.14); two altitude transects, on Aucellabjerg and on the mountain Zackenberg; and a coastal flat. Soil below the BSC was also collected for soil texture and chemistry measurements. An extensive sampling of laminar macrocolonies of the *Nostoc* cf. *commune* type (figure 6.15) were sampled from many places along the valley and on the coastal flat, covering the macromorphological diversity of the site. Cyanobacterial/algal and microfungal endoliths (figure 6.16) and epiliths were sampled from big boulders with different mineral composition. Mats were sampled around the shores of the small moraine lakes on the right side of the river, from streams and seepages and snow-melting areas on the Aucellabjerg, and on the wet flat along the coast. Fluorescence kinetics was measured on freshly collected microalgal mats in the station laboratory.

Work on course in the team member's laboratories: At present, analytical procedures are carried out on the amount of collected samples. We began to analyse the cyanobacterial laminar macrocolonies with the aim to isolate and identify their principal components and to answer topical questions about the clonal or mixed composition of the single lamina. We will compare the collected samples with other laminar macrocolonies collected in previous years from Greenland (sites around Arctic Station, Disko), Svalbard, Scandinavia and Iceland to determine the biogeographic distribution in the Arctic of the species making up the laminar macrocolony, presumably *Nostoc* cf. *commune*. EPS will be extracted from the BSC and water movement mediated by the EPS matrix determined. In addition, the effects of the presence of BSC on protosoil formation and development will be studied. Microfungi and cyanobacteria will be identified and characterised also with the application of a metagenomic approach. Isolation of strains of microfungi and cyanobacteria from rock samples is in progress.

6.8 Three years exclusion of large herbivores in a high Arctic mire changed vegetation structure and greenhouse gas balance

Julie M. Falk, Niels Martin Schmidt, Torben R. Christensen and Lena Ström

Half of the Earths land surface is influenced by large herbivores; livestock or native (Olff et al. 2002) and their presence can have great influence on the ecosystem (e.g. Mulder 1999, Tanentzap and Coomes 2012). In the Arctic, herbivory has been shown to have an important impact on the carbon cycle (e.g., Cahoon et al. 2012, Falk et al. 2014, Sjögersten et al. 2011, Van der Wal et al. 2007 and Welker et al. 2004). The impact of grazing on the carbon balance, however, seems somewhat ambiguous. Most studies have shown a decrease in net

Figure 6.17 Exclosure four 2 July 2013. Photo: Julie M. Falk.

primary production (NPP) (e.g., Cahoon et al. 2012, Elliott and Henry 2011, Ouellet et al. 1994, Sjögersten et al. 2011 and Van der Wal et al. 2007) while other studies has shown that grazing may lead to an increase in NPP (Cargill and Jefferies 1984, Olofsson et al. 2001 and Olofsson et al. 2004). The difference seems related to ecosystem type and grazing pressure. In 2010, an *in situ* field experiment was initiated in Zackenberg. The aim of the experiment was to study the effects herbivory have on the vegetation and carbon balance by excluding musk oxen *Ovibos moschatus* grazing from parts of the ecosystem. The set-up consists of five block replicates with three treatments within each block, i.e., control, exclosure and a snow-control (the treatment area is 10×10 m and the fences are 1 m high). During the growing season, we have since 2011 carried out weekly measurements of CO_2 and CH_4 fluxes and ecosystem properties, i.e., water table depth, active layer depth and soil temperature. In 2011 and 2013, a detailed analysis of the vascular plant species composition and density within each measurement plot was carried out. In 2013, biomass samples 20×20 cm were harvested within all treatment areas.

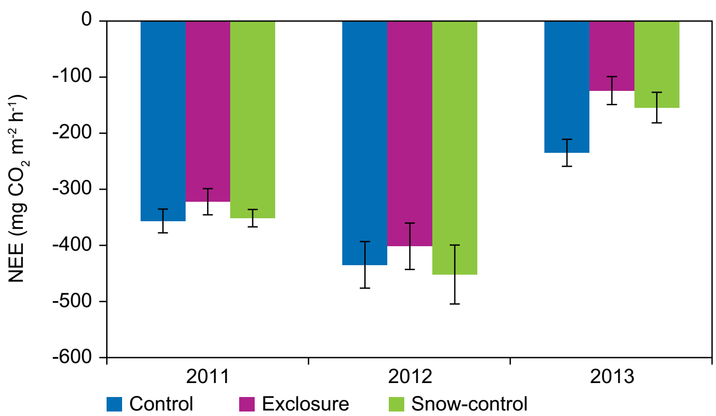


*Figure 6.18 The mean net ecosystem exchange (NEE) (mg CO_2 m^{-2} h^{-1}) ± SE, for 2011, 2012 and 2013 for controls, and the two treatments: exclosure and snow-control. Data is based on all blocks and all treatments; control n =15, exclosure n=16 and snow-control n=8. The significance for the differences between control and treatments are indicated with asterisk above the bars, *** $p \leq 0.001$, * $p \leq 0.05$*

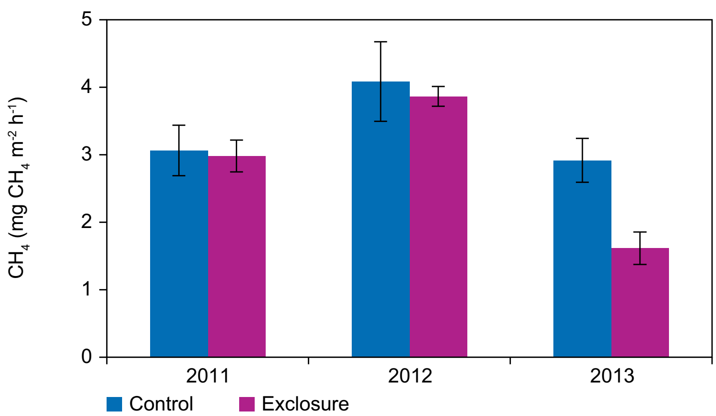


*Figure 6.19 The mean CH_4 flux (mg CH_4 m^{-2} h^{-1}) ± SE, for 2011, 2012 and 2013 for controls and exclosures. Data is based on plots from the two wet blocks (3 and 4), control n=7, exclosure n=7. The significance for the differences between control and exclosure are indicated with asterisk above the bars, *** $p \leq 0.001$*

The third year after the initiation of the experiment a clear effect of excluding musk oxen from the ecosystem was found. The total number of vascular plant tillers and *Eriophorum scheuchzeri* (ES) tillers had decreased substantially in ungrazed areas, with 33-44 % and 51-53 %, respectively. Moss growth had on the other hand increased with 35 % and the standing old biomass (litter) with 70 % in ungrazed areas (see figure 6.17). Further, the mean height of the vascular plants and of (ES) plants had increased significantly. The mean greenhouse gas fluxes were significantly lower in exclosures: CO_2 with 47 % (figure 6.18) and the CH_4 emission with 44 % (figure 6.19).

In conclusion, removing musk oxen grazing rapidly resulted in dramatic changes to the ecosystem. The carbon allocation patterns in the ecosystem changes both in terms of vegetation composition and structure, and greenhouse gas fluxes. Mosses became more dominating, presumably since tramping by musk oxen normally compress the moss layer and decrease its thickness. The thicker moss layer forces vascular plants to grow taller leaves due to competition for light. Additionally, musk oxen grazing decrease the number of flowering plants and seem to stimulate tiller formation. The lower number of vascular plants presumably explains the decrease of CO_2 uptake, while the decrease in CH_4 emission most likely is connected to a combination of lower CO_2 uptake, less vascular plants and lower overall carbon allocation below ground and hereby less root exudation and substrate availability for CH_4 production (6.19).

The future of the musk ox population in a changing Arctic environment is uncertain, this experiment is pointing towards the potentially large effect that herbivory has on the carbon balance of natural ecosystems in the Arctic.

6.9 Studies on controls of biogenic volatile organic compound emissions in the high Arctic Greenland

Riikka Rinnan, Sarah Hagen Svendsen and Frida Lindwall

A wide range of biogenic volatile organic compounds (BVOCs) are emitted from plants and soils worldwide. In addition, the high Arctic ecosystems emit measurable quantities of BVOCs, and the composition of these emissions differs between vegetation types (Schollert et al. 2014). BVOCs have both warming and cooling effects on climate via complex atmospheric feedback mechanisms, including the influence on the oxidation capacity of the atmosphere and secondary organic aerosol formation. As Arctic ecosystems are facing rapidly proceeding climate warming with likely strong effects on BVOC emissions – both directly and indirectly via vegetation changes – (Rinnan et al. 2014), our aim is to assess controls of BVOC emissions in these ecosystems in studies extending over several years.

During the 2013 growing season, our specific aims were to assess how the BVOC emissions vary over a soil moisture gradient, determine the dial fluctuations in BVOC emissions, and to estimate the significance of emissions from leaf litter. BVOC emissions were measured using an enclosure technique and trapping of the BVOCs in adsorbent cartridges followed by laboratory analysis of the samples by gas chromatography-mass spectrometry (Faubert et al. 2010).

The preliminary data from the soil moisture gradient suggests that the BVOC emissions were low in the driest and wettest plots relative to the intermediate ones (figure 6.20). Integrating results from vegetation analysis with the emission data will enable us to further identify characteristics in emissions from the different vegetation types along the gradient.

The dial fluctuations in BVOC emissions from *Salix arctica* and *Cassiope tetragona*-dominated heaths were assessed by measuring the emissions over 24 hour periods. The emissions correlated with temperature and photosynthetically active radiation (PAR), and due to the low temperature and PAR (despite midnight sun), there were hardly any BVOC emissions during the night (Lindwall et al. unpublished data).

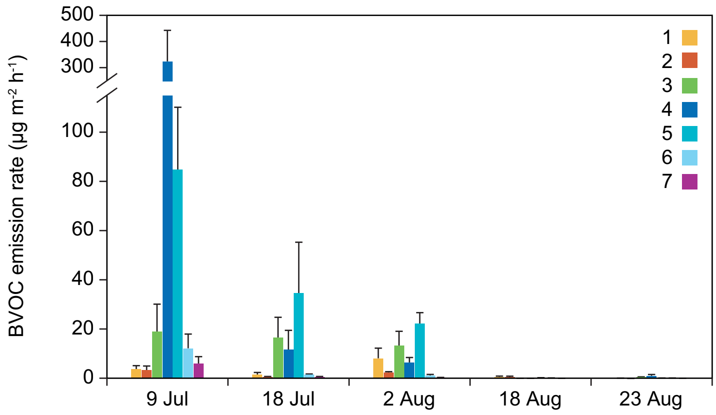


Figure 6.20 Total biogenic volatile organic compound (BVOC) emission (mean + SE, n = 3) from a soil moisture gradient extending from dry Dryas-dominated and bare soil plots (1) to a wet fen (7).

The contribution of BVOC emissions from soil and litter to ecosystem BVOC emissions was studied in an experiment established in 2012 with three different treatments: litter removal, litter addition (doubling of the litter biomass) and unmanipulated controls. An additional study to investigate BVOC emissions during different stages of litter decomposition and under different climatic conditions was also set up in autumn 2012. Litter bags with local litter of *S. arctica* and *C. tetragona* were placed on experimental plots with different climate change treatments (figure 6.21), and the litter mass loss, chemistry and BVOC emissions are studied over several years of decomposition. A deeper understanding of BVOC emissions from litter is important because litter forms a considerable part of the above ground carbon mass in the Arctic. Furthermore, a warmer climate will increase the expansion of deciduous vegetation in the Arctic, which in turn will increase the leaf litter fall.

Figure 6.21 Litter bags incubated within the litter layer in a study assessing BVOC emissions from different stages of litter decomposition. Photo: Michelle Schollert.

6.10 Potential plant acquisition of nitrogen from thawing permafrost soils

Anders Michelsen, Daan Blok and Bo Elberling

In order to study potential plant uptake of nutrients and nitrogen (N) in particular from thawing permafrost soils, a trace amount of the naturally occurring nitrogen isotope ^{15}N was added in August 2012 in 10 spots for each of three soil depths (10, 45, 90 cm), to study plant uptake at high depths. The study took place in an open *Salix arctica* – *Dryas* spp. – *Kobresia myosuroides* vegetation on a plateau 300 m south of the research station, where the maximal active layer depth is approximately 90 cm. As little as 3 g of N was added in total in the experiment, in order to avoid adding fertilizing amounts, which may disturb the ecosystem. Soon after injection of the label in August 2012, limited leaf harvesting took place to verify if quick plant nitrogen uptake was detectable.

In August 2013, leaves of *Salix arctica*, *Dryas* spp. and *Kobresia myosuroides* were harvested in a small area around each injection point, to study uptake of ^{15}N at different depths, added one year earlier. Furthermore, small soil samples were collected for analysis of total N, dissolved N and microbial N at depth intervals in the soil, and fine roots were also sampled for analysis. The samples are currently being analysed with isotope ratio mass spectrometry (IRMS), and preliminary results show high N uptake by roots at many depths. The ^{15}N content of roots and adjacent soil will be compared to verify plant uptake of N at different depth, and to investigate the function of roots as suppliers of nutrients and water in different soil layers. Moreover, plant species specific differences in N uptake can be revealed.

The overall aim of the study is to assess the effect of permafrost thaw on vegetation development and nitrogen availability at plot and landscape level, and to address fundamental research questions regarding plant nutrient acquisition.

6.11 East Greenland bryophytes – biodiversity and importance as herbivore diet (BRYOGREEN)

Michael Stech and Hans (J.D.) Kruijer

Bryophytes are important components in Arctic tundra ecosystems in terms of biomass, productivity, species diversity, and herbivore diet compositions of migratory goose species during the summer breeding period. Furthermore, bryophytes are ideal candidates for investigating the impact of global climate change, which is foreseen to affect the Arctic particularly strongly. However, Arctic bryophyte species are often difficult to identify morphologically due to unusual growth forms in response to the harsh environment. BRYOGREEN aims to infer the importance of bryophytes as diet component of herbivores in East Greenland in comparison with Svalbard, to analyse patterns of relationships and genetic diversity in bryophyte species across the Greenland Sea, and to develop molecular species identification tools (DNA barcoding) that make bryophytes in East Greenland fully accessible to biodiversity-based ecological research and studies of the responses of Arctic vegetation to climate change and pollution.

During fieldwork in July 2013, 335 samples (285 bryophyte and 50 faeces samples) were collected at 77 localities in the Zackenberg valley. In addition to faeces of barnacle goose and musk ox, we were able to collect faeces from Arctic hare, northern collared lemming, rock ptarmigan, and snow bunting. Bryophyte vegetation studies were carried out focusing on *Cassiope* heath and *Salix* snow bed vegetation in the surroundings of the station, where four transects of 21 plots (20×20 cm) each were recorded by plant sociological relevés according to the Braun-Blanquet approach.

Microscopic identification of the collected bryophyte samples, and analyses of the species composition and cover of the sampled vegetation plots are in progress. First results indicate that the Zackenberg bryophyte flora is more similar to that of East Svalbard (Edgeøya) than to West Spitsbergen.

The moss genus *Bryum* (figure 6.22) was chosen for a first detailed molecular study, because 1) *Bryum* is a large and

Figure 6.22 Cushions of red-coloured Bryum *plants on wet tundra at Zackenberg. Photo: Michael Stech.*

widespread genus with high species diversity in the Arctic, 2) developing molecular species identification tools based on DNA markers is urgently needed since *Bryum* species are particularly difficult to identify morphologically, and 3) a large molecular dataset of *Bryum* species from Svalbard is already available. DNA markers (chloroplast *trnT-trnL-trnF* and nuclear ribosomal ITS regions) are currently being generated from the *Bryum* collections of Zackenberg for comparisons of molecular diversity between East Greenland and Svalbard. An analysis of the diet composition of herbivore faces samples based on chloroplast and nrITS sequences generated by next-generation environmental sequencing is in progress as well, which will – in the case of barnacle goose – be compared with corresponding data from Svalbard. We expect to publish results on species delimitations in *Bryum* and herbivore diet compositions by the end of 2014. A detailed comparative study of the bryophyte vegetation at either side of the Greenland Sea will be completed after planned fieldwork on Edgeøya (SEES expedition) in 2015.

6.12 ZackSAR – retrieval of environmental parameters in Arctic tundra landscapes from remote sensing data

Jennifer Sobiech-Wolf

In the vast uninhabited Arctic regions, *in situ* monitoring of environmental parameters is expensive and a logistic challenge. Remote sensing allows to monitor large areas cost efficient in near real time. Remote sensing with Synthetic Aperture Radars (SAR) is especially useful, as these sensors deliver data independent of sunlight and cloud cover. However, to understand the SAR data, precise validation is necessary. For permafrost and tundra regions, data validation is so far not sufficient. Zackenberg valley is a suitable place for evaluation studies, as an excellent ongoing monitoring network of climatic, bio- and geological parameters exists and with the presence of different soil types and vegetation communities in the study area. One SAR image, recorded by the German TerraSAR-X satellite over Zackenberg in the high resolution Spotlight mode, is shown in figure 6.23.

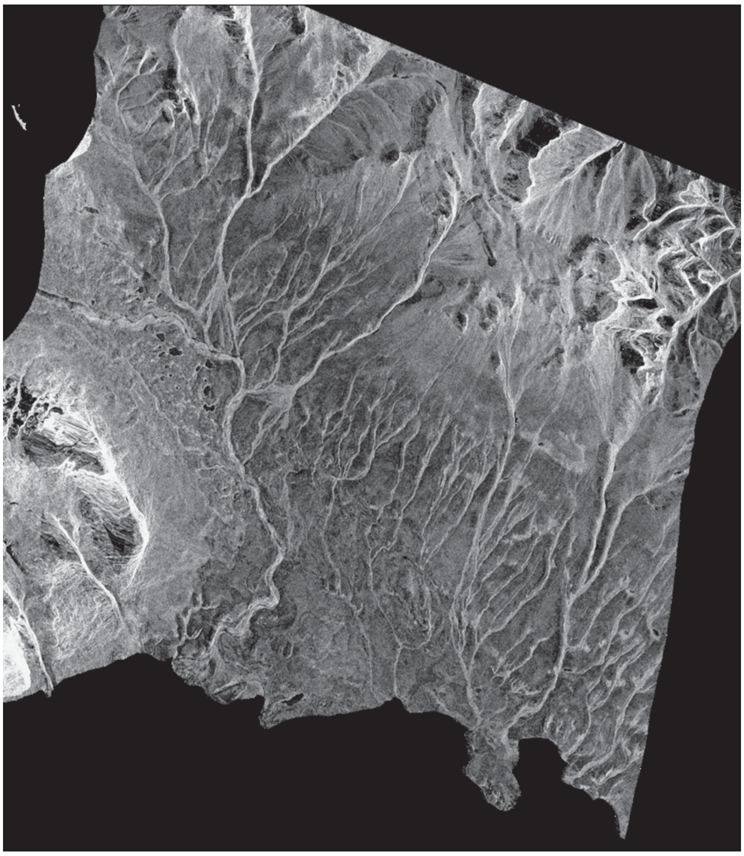


Figure 6.23 Geocoded and calibrated TerraSAR-X image of the Zackenberg valley, recorded at 28 June 2013. Image provided by DLR.

Important parameters influencing the radar signal are, beside others, the soil moisture, the vegetation water content, and the structure of the vegetation. To obtain an extensive dataset to validate the radar images, soil moisture was measured with a portable HS2 Hydrosense instrument with 12 cm rods (figure 6.24A) at more than 6000 locations distributed in the different land cover units present in the Zackenberg valley within four weeks in July and August 2013. The measurements were carried out either randomly or along 100 m transects with one measurement each meter. Some profiles were revisited weekly to monitor the moisture change over time.

In addition, sixty above ground biomass samples were harvested in 20×20 cm plots (figure 6.24B). Twenty sites, distributed over the valley and with different ecosystem types present in the area, were visited. Three replicates were taken at each site to catch the variability at each site. All samples were oven dried to determine the total vegetation water content. Afterwards, the biomass samples were sorted in the classes “moss”, “grass and herbs”, and “woody biomass” to get information of the vegetation structure.

For land cover evaluation, more than 2000 GPS tagged photographs were taken, each covering approximately 1 m² of the land surface (see figure 6.24C).

First analysis of the SAR backscatter values of the TerraSAR-X images and the environmental parameters soil moisture, vegetation moisture, and land cover showed no clear correlations. The next step of the project is to evaluate SAR images from other satellites with sensors operating with longer wavelength such as RADARSAT-2 (C-band) and ALOS PALSAR 2 (L-band).

6.13 Modelling past and future vegetation communities

Lærke Stewart, Loïc Pellissier, Caroline Ernberg Simonsen and Niels Martin Schmidt

Future climate change is predicted to be particularly strong in the Arctic (IPCC 2013), and biological impacts are therefore expected to be greater in this biome. Since plants constitute the basis of terrestrial ecosystems, changes in the abundance and composition of plant communities are likely to have cascading effects throughout food webs. To be able to forecast future effects of climate change on plants it is essential to understand current and historical distributions.

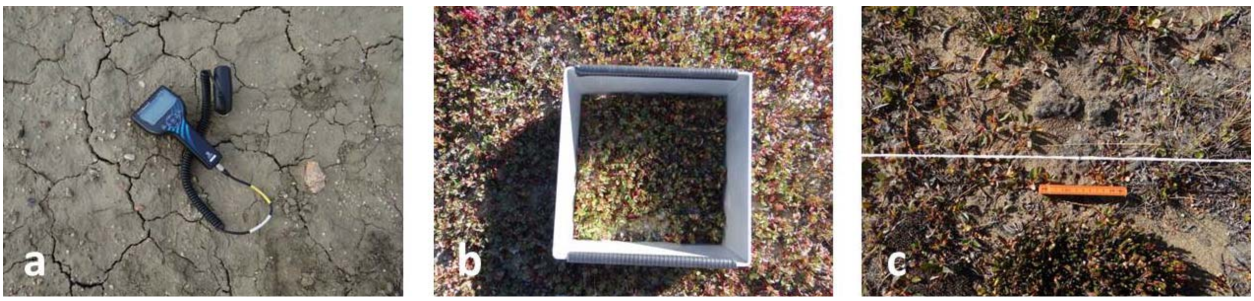


Figure 6.24 a) HS2 Hydrosense soil moisture measurement tool. b) Exemplary plot for biomass sampling, c) Land cover photograph. Photo: Jennifer Sobiech-Wolf.

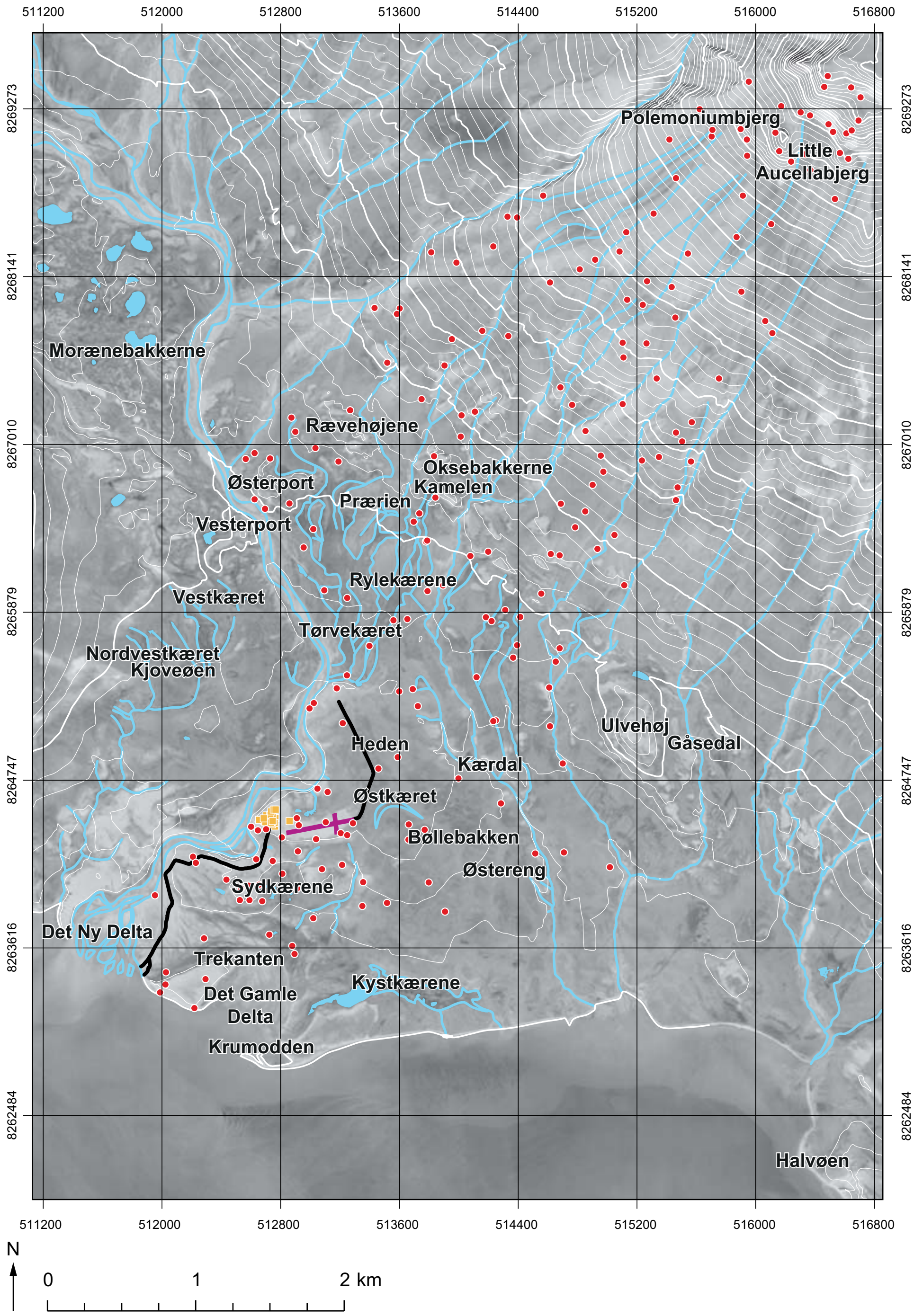


Figure 6.25 Map of the Zackenberg Valley showing the location of the 200 plots.

Based on data collected in Zackenberg during summer 2013 we will build a vegetation model for the valley that can be projected into the past as well as the future. Data was collected within an area of approximately 25 km^2 running up the slopes of Aucellabjerg. The lowland vegetation is dominated by *Cassiope tetragona* heath intersected by grasslands and *Salix arctica* snow beds in the low-lying depressions. Further up the slopes the vegetation changes, and grasslands, *Dryas* heaths and fell-fields are dominating (Bay 1998). Abrasion plateaus are present throughout the whole study area. In total, 200 plots were randomly stratified on a combination of elevation classes and vegetation classes (figure 6.25). Within each plot we measured several physical and chemical parameters as well as produced full species lists of all vascular plants and estimated the cover (based on the Braun Blanquet cover scale) of all recorded species. The cover of bryophytes and lichens were likewise estimated.

To model the distribution of plant species we will use species distribution models (Guisan and Theurillat 2000) which links species observations to environmental predictors. Species distribution models will be fitted for each species against a set of topoclimatic predictors. We will model the distribution of species using stacked species distribution modelling (S-SDM, (Guisan and Rahbek 2011)). In S-SDMs the distribution of each species is first predicted independently and the distributions are then stacked to predict species assemblages. This can provide both species richness and composition for each modelled unit (Dubuis et al. 2011). Under the assumption of niche conservatism (Pearman et al. 2008), these models can be projected into the past and future using different climatic maps as input, and potential distributions of species can be inferred.

As environmental predictor variables, temperature, soil moisture, pH, snow cover and topography will be used. For future scenarios the most recent climate simulations from IPCC will be used (IIPC 2013). These are at a coarse resolution (i.e. one cell for the Zackenberg valley) and give temperature and precipitation for each month from now and to the year 2100. Under the assumption that everything will change uniformly, we will downscale the current climate, snow and soil variables. When we have future scenarios for all of these variables, we can then use the vegetation model to predict future changes in distribution and cover of all vegetation communities. The data is currently being processed and results are expected during 2014.

6.14 GPS collaring of musk oxen at Zackenberg

Niels Martin Schmidt, Mikkel Stelvig, Jesper Bruun Mosbacher, Lars Holst Hansen and Carsten Grøndahl

Musk oxen are the only large herbivore in the National Park in North-east Greenland, and play a central role there as both grazer and food base, though the latter in the absence of wolves is merely through carcasses. While the demography and distribution of musk oxen at Zackenberg in summer is well-studied through the on-going monitoring in the valley, their whereabouts during the long, harsh winter is practically unknown. In late autumn 2013, a team of biologists and a veterinarian from Aarhus University and Copenhagen Zoo therefore set out to capture 14 female musk oxen and equip these with GPS collars, thus enabling us to follow these individuals year-round for a minimum of one year (figure 6.26).

Luckily, the density of musk oxen was extremely high during October 2013, and the team was able to capture all 14 adult cows within six days of field work. We therefore applied to the Government of Greenland, and were granted permission to capture six adult musk ox bulls. The bulls were not equipped with GPS collar. All musk oxen were captured within the Zackenberg valley.

All anaesthetization, handling, sampling and GPS collaring was carried out without major problems. From each individual, a number of samples were taken. These included bodyweight and samples

Figure 6.26 Collaring of adult musk ox cow in Zackenberg valley, October 2013. Photo: Lars H. Hansen/ARC-PIC.com.

Figure 6.27 Musk ox #2 that died during spring 2014 close to Daneborg. Photo: Stine H. Pedersen.

of blood, tissue, hair and hoof, faecal droppings and conjunctiva swabs. The samples will be analysed to infer kinship, health status, diet etc.

Currently (spring 2014), all GPS collars are working. One cow has died (figure 6.27), but we were able to retrieve the collar. During winter, the musk oxen have mainly been utilizing the valleys lowland across Wollaston Forland, and most of the time close to the coast. Most of the collared musk oxen have spent the winter outside the Zackenberg valley, and are still outside the valley, but will hopefully return during summer.

6.15 Dissecting the interaction web of Zackenberg: targeting pollinators

Kristiina Visakorpi, Malin Ek, Gergely Várkonyi, Helena Wirta, Bess Hardwick, Peter Hambäck and Tomas Roslin

In 2103, we continued our work on dissecting the overall food web of Zackenberg by multiple methods (cf. Roslin et al. 2012, Várkonyi and Roslin 2013, Roslin et al. 2013 and Wirta et al. 2014). As new initiatives for this year, we took on the challenges of applying our previously-developed DNA-barcodes to identifying the feeding associations of birds and the diets of spiders. We also conducted large-scale manipulations of arthropod predator densities to explore the potential for trophic cascades reverberating through the food web.

Much additional work was spent on preparing for a future venture – expanding into the plant-pollinator part of the local interaction web. Here, we invested specific effort into exploring the associations between an abundant plant, avens in the genus *Dryas* (Rosaceae), and its insect pollinators.

Cushions of avens dominate many parts of Arctic vegetation. During flowering, they offer food for a major fraction of both pollinators and herbivores (Roslin et al. 2013). Being widespread from the mountains of Central Europe to the highest Arctic (Elkington 1971, Skrede et al. 2006), avens constitutes a plant resource of global importance. For pollination, it has been assumed that avens relies on insects. Consequently, variation in the structure of the pollinator community has been hypothesized to reflect directly into variation in rates of avens seed set (Kevan 1972). With a change in pollinator communities across the Arctic (e.g. Høye et al. 2007, 2013), the ecosystem function of avens pollination may then be set to change – a prediction, which we will test through experimental work (Spatial Foodweb Ecology Group 2013).

To critically examine the fundamental assumption that avens rely on insects for pollination, we manipulated the access of pollinators to a set of individual flowers. More specifically, we used three treatments to prevent pollination by different agents:

- To prevent both insect and wind pollination, we placed small plastic jars over unopened buds of avens (figure 6.28A).
- To exclude only insect pollinators, while allowing wind-dispersed pollen to enter the flower, we built small tents out of dense net-like fabric (mesh size less than 1 mm) and placed them over the buds (figure 6.28B).

- To compare the effects of the two pollination exclusions to pollination success under natural conditions, we used control flowers. These flowers were left uncovered and marked with a small circle of thin iron wire (figure 6.28C).

Excluding either wind or both wind and insect pollinators significantly decreased the seed production of avens as compared to open control flowers ($\chi^2 = 10.9$, $df = 2$, $p = 0.004$). Under both of the pollination exclusion treatments, only 16.7 % of flowers produced seeds, whereas the clear majority (61.1 %) of the open control flowers produced seeds (figure 6.29). Allowing wind pollination while excluding insect visits did not increase the amount of seed production, and thereby both exclusion treatments seemed to have an equally detrimental effect on the seed production of avens. Overall, we were then able to conclusively establish that seed set in avens is significantly augmented by insect pollination.

In addition to assessing the role of insect pollinators of avens, we also developed the methods for sampling such pollinators at a large spatial scale. In a pilot experiment, we compared catches of insects among different types of trap flow-

Figure 6.28 Experimental setup used to study the pollination biology of avens, showing A) exclusion of both wind and insect-pollination, B) exclusion insects but not wind and C) a control flower, left open for all types of pollination. Photos: Malin Ek.

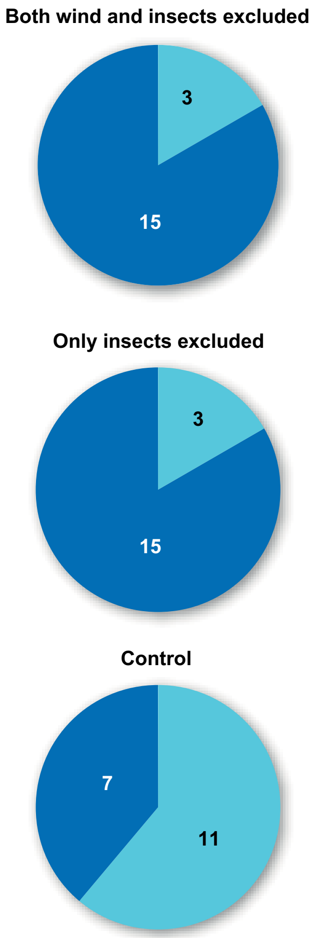


Figure 6.29 Seed set of mountain avens under experimental conditions. Here, the slices of the pie charts represent the numbers of flowers that did or did not produce seeds under different experimental conditions (for a visual representation of treatments, see figure 6.28).

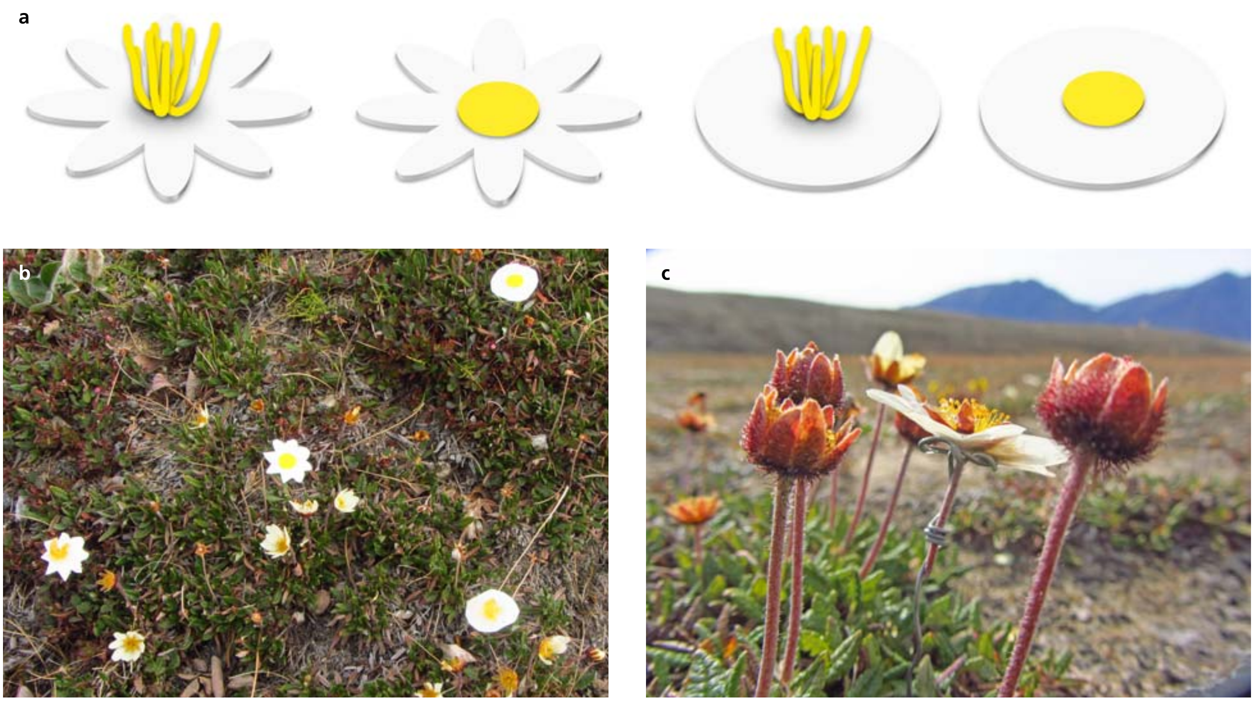


Figure 6.30 Trap flower designs compared in a pilot experiment. Sticky trap flowers were made out of white "sticky traps" (plastic board covered with glue). Four different designs (a) were tried in a pilot experiment (see b for trap flowers in the field). Here, two shapes of flower (eight petals vs round) were factorially combined with two kinds of stamens and pistils (yellow wool yarn covered in glue and round yellow sticky trap; see a). In addition, we also tried different versions of covering real flowers, or parts of them, with sticky glue (Temmen GmbH, Hattersheim, Germany; see c). As flowers of all kinds attracted insect assemblages characterised by similar abundances and composition, and as trap designs with petals partly prevented the insects from sticking to the traps, we opted for the simplest trap design (see a, sketch at the extreme right). Photos and drawings: Malin Ek.

ers (figure 6.30). In 2014, the findings from these pilot experiments will be directly applied in implementing a large-scale collaboration among Arctic Research stations, the Global *Dryas* Project (Spatial Foodweb Ecology Group 2013).

6.16 Seasonal patterns in nest predation risk in sanderling *Calidris alba*

Jeroen Reneerkens

Arctic migratory birds synchronize their reproduction with the seasonal abundance and availability of Arctic arthropods for an optimal growth of their offspring (Schekkerman et al. 1998, 2003; Meltofte et al. 2007). Recent climate change has advanced the emergence of arthropods considerably (Høye et al. 2007). Late arrival in spring may result in a mismatch between demands for growth and the availability of food resources (McKinnon et al. 2012). Indeed, the latest hatching sanderlings *Calidris alba* in Zackenberg each year showed a reduced growth and consequent survival (Reneerkens et al. 2014). Migratory birds have been suggested to be constrained by a rigid control of the annual cycle or by circumstances encountered during migration, which prevent them to arrive earlier at the breeding grounds and advance the start of reproduction in pace with the advancing food peak (Knudsen et al. 2011).

In the top-down structured food web of the high Arctic, predation is an important selective pressure shaping the life histories of ground-breeding birds (McKinnon et al. 2010, Legagneux et al. 2014). Predation pressure on bird nests by the main generalist predator, Arctic fox *Vulpes lagopus*, probably changes during the course of the spring when different prey becomes profitably available (Roth 2002). It has also been suggested that it is easier for Arctic foxes to find shorebird nests when the snow-free area where shorebirds lay their clutches is limited (Byrkjedal 1980).

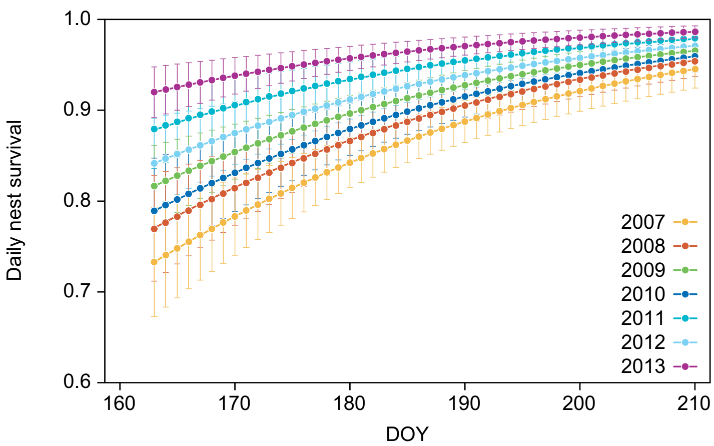
During summers 2007-2013 we searched for sanderling nests, which were aged using the flotation method (Hansen, Schmidt and Reneerkens 2011). The fate of each nest was determined using small thermo loggers in the nest cup (Reneerkens et al. 2011) or by frequent visits to the nest. Clutches that were abandoned or failed for other reasons than depredation were

Figure 6.31 A sanderling about to incubate its clutch of four eggs (25 June 2013). Fox predation of eggs selectively favours late clutches whereas an increasingly early emergence of arthropods forces sanderlings to breed earlier. Photo: Jeroen Reneerkens.

excluded from the analyses. We collected data on 194 sanderling clutches (figure 6.31) and carried out a nest survival analysis in programme Mark (Dinsmore, White and Knopf 2002) using year, date, date + date2 as covariates. Models were ranked with Akaike's information criterion for small samples (AICc), and ΔAICc and Akaike weights (wi) were used to infer support for models in the candidate set (Burnham and Anderson 2002).

The model, which received most support, showed an additive effect of year and date. In other words, year and date explain the variation in nest survival best together. In each year, nest survival increased with date (figure 6.32). This suggests that Arctic foxes and other predators of bird eggs focus on eggs and/or are most successful in finding bird nests early in the spring when the snow-free area is small. Later in the season, other prey becomes available (e.g. Arctic char *Salvelinus alpinus* from the river Zackenberg) and the density of bird nests becomes smaller due to hatching and earlier predation. The seasonal increase in nest survival selectively favours later clutches, but the climate change induced advancing abundance of arthropods favours earlier nest initiation (Reneerkens et al. 2014). Nest predation can thus be an additional constraint on the advancement of phenology of Arctic birds, making them extra vulnerable for climatic changes of the Arctic environment.

Figure 6.32 Predicted daily sanderling nest survival of the most parsimonious model in per day of year in 2007-2013 in Zackenberg.



6.17 Ecology of Arctic lakes

Kirsten S. Christoffersen

Ecology of lakes and ponds in the Zackenberg valley has been studied for a number of years with focus on how the overall seasonal variations in environmental parameters affect water chemistry, plankton and benthic populations. A majority of the lakes and all ponds in the area are shallow, which implies that benthic communities are the most productive compartment of the ecosystem. Aquatic mosses and benthic diatoms are the common primary producers and form therefore also a potential important food resource for other biota such as chironomid larvae, tadpole shrimps and zooplankton. However, the grazing of live moss plants seem to be negligible and the main loss rate is thus through decomposition microorganisms (bacteria, fungi and invertebrates) in combination with abiotic forces such as waves and ice.

In a previous study of mosses in Sommerfuglesø it was shown, by Riis et al. (2014) that the observed annual mean production *of Drepanocladus trifarius* was about 2-3 mg DW shoot year^{-1} expressed as biomass increase and 10-30 mm shoot year^{-1} expressed as length increase, while the age of most shoots was 7-10 years. About 90 % of the variation in annual net production was explained by between-year variability in snow prolongation and net radiation in June. However, very little is known about the loss rates of moss plants in Arctic lakes and ponds.

The activities in 2013 included termination of an experiment started in 2012 in two lakes (Sommerfuglesø and Langemandssø) that aimed to determine 1) annual degradation rates of aquatic mosses and 2) the annual accumulation of epilithic benthic algae. Additionally, both lakes are equipped with a set of data loggers that are continuously measuring light, oxygen and temperature. This setup is part of an ongoing experiment that aims to develop techniques that require as little man power as possible in terms of manual sampling and analyses. The data loggers will also provide important information for the moss degradation experiment (ice in and out, light attenuation etc.).

The first objective was carried out as a traditional litter bag experiment. A number of moss branched of the dominating species in Sommerfuglesø (*Drepanocladus trifarius*) and Langemandssø (*Scorpidium scorpioides*) were collected in the lakes in late August 2012. Each branch was rinsed, trimmed to an approximately size of 5 cm, weighed and let to dry at 50 °C for 24 hours. The dried material was weighed and re-moistured before grouped randomly in five samples placed in plastic mesh bags with mesh nets of 200 and 2000 µm respectively (figure 6.33). The second objective was carried out using unglazed ceramic tile as a surrogate substrate for epilithic algae. One tile (1×1×0.2 cm) was placed in each of the bags. The bags were sealed and placed in a coarser mesh net, which was incubated in the littoral zone at approximately 0.5 m in Sommerfuglesø and Langemandssø in the beginning of September 2012, respectively. The lake had already a thin layer of ice at that time (figure 6.34).

All mosses and tiles were successfully retrieved in late August 2013. The wet and dry weights of individual moss branches were determined and the average loss of material in each of the mesh bags could be calculated. The tiles were stored frozen until analyses could take place. The chlorophyll content of each tile was determined after extraction with ethanol and spectrophotometrical readings at 665 and 750 nm.

The average loss rate of dry weight was 13-21 % of the initial material over one year (table 6.2). There was no significant difference in the loss of dry weight between the two moss species and between mosses incubated in 200 and 2000 µm net. The latter indicates that microorganisms were responsible for the decomposing. Interestingly, the decomposition rate is of the same order of magnitude as found for other aquatic plants in subarctic lakes.

The tiles had detectable amounts of chlorophyll but there were larger variations between individual tiles (table 6.3) and thus no significant difference between the tiles incubated in 200 and 2000 µm nets, respectively. The average amount of accumulated chlorophyll within one year was 168 µm m^2.

Figure 6.33 Litter bags with mesh sizes of 200 and 2000 µm were used for the decomposition experiment. Photo: Kirsten S. Christoffersen.

Figure 6.34 Litter bags ready to be deployed in Sommerfuglesø at a depth of approximately 0.5 m. Stones are used as counter weights to ensure the bags stayed at the bottom. Photo: Kirsten S. Christoffersen.

Table 6.2 The percentage loss of dry weight (% of the initial amount) over one year of mosses incubated in 200 and 2000 µm mesh nets, respectively. The values are averages (n = 10) and the SD is given in parentheses.

Lake	Moss species	Loss of moss litter dry weight (% of initial)	
		200 µm net	2000 µm net
Sommerfuglesø	*Drepanocladus trifarius*	16% (± 10)	15% (± 5)
Langemandssø	*Scorpidium scorpioides*	21% (± 7)	13% (± 5)

Table 6.3 The accumulated amount chlorophyll over one year from epilithic algae based on ceramic tiles. The values are averages (n = 5) and the SD is given in parentheses.

Lake	Chlorophyll (µm m²)	
	200 µm net	2000 µm net
Sommerfuglesø	89.7 (± 73.8)	228.0 (± 255.7)
Langemandssø	165.0 (± 78.4)	188.4 (± 31.6)

Since very few data exist on moss decomposition as well as on epilithic biomass accumulation in Arctic lakes the data obtained from Sommerfuglesø and Langemandssø is valuable for our understanding of how much carbon primary producers contribute with to the overall carbon budget. These data will be further analysed and matched with measurement of light, oxygen and temperature that has been recorded continuously in both lakes using various type of data loggers.

6.18 Trophic interactions, temperature and greening in a changing climate

Anders Gravbrøt Finstad, Ditte Katrine Hendrichsen and Erland Birkeland Nilsen

Arctic freshwater ponds and lakes are important sentinels of climate change as they represent complete, delimited ecosystems within extensive terrestrial landscapes that are expected to undergo large changes. Terrestrial vegetation structure and dynamics has major impact on aquatic production and biodiversity through its influence on run-off patterns, nutrient and carbon fluxes. Consequently, expected climate driven changes in terrestrial primary productivity may modify the influx of nutrients to aquatic systems and alter primary production resulting in changes also in higher trophic levels (Hessen et al. 2009, Woodward et al. 2010). Moreover, temperature directly affects physiological performance in heterothemic organisms, and temperature changes due to climate change are thus predicted to have both direct and indirect effects on trophic interactions and ecosystem productivity (Christoffersen et al. 2006, De Senerpont Domis et al. 2012).

In the present project, we aim to test how trophic interactions in Arctic freshwaters are shaped by temperature and productivity, mediated both through run-off from terrestrial catchments and temperature changes. The project uses a space-for-time approach to study the impact of terrestrial vegetation on lake/pond water chemistry and further its impact on trophic interactions. Data consist of repeated measurements of densities of main components of the ecosystem in small Arctic lakes with three- or four trophic levels along temperature and productivity gradients.

During the summer 2013 (July-August) a field campaign was conducted where 21 ponds/small lakes in the Zackenberg and Daneborg area where sampled four times each, with respect to water chemistry (total nitrogen, phosphorous and carbon), zooplankton and chlorophyll *a*. Vegetation coverage and composition in the catchments of each pond was quantified using a quadrat approach. Temperature was logged continuously in each lake/pond throughout the study period. We also delineated the perimeter of the ponds and lakes and measured maximum depth where that information not could be found in the literature. In addition, semi-quantitative samples of *Lepidurus arcticus* (using Z-sweeps) where taken twice in each pond. Zooplankton biomass was derived from published length-weight relationships. The lakes and ponds ranged in size from 2500 to 147000 m² and depth from 50 to more than 300 cm.

Preliminary analysis show a positive correlation between the percentage of vegetation cover in the surrounding terrain of the lakes/ponds and total nitrogen and phosphorous (figure 6.35a) as well as total organic carbon. Phytoplankton biomass (measured using chlorophyll *a* as a proxy) where positively correlated with water temperature (figure 6.35b), total phosphorous (figure 6.35c), and nitrogen. Total zooplankton biomass increased with phytoplankton biomass (figure 6.35d).

6.19 Nutrient fluxes and biotic communities in Arctic rivers with different water source contributions

Alexander Milner, Catherine Docherty and David Hannah

Arctic river ecosystems are influenced significantly by cryospheric and hydrological processes. Strong links are evident

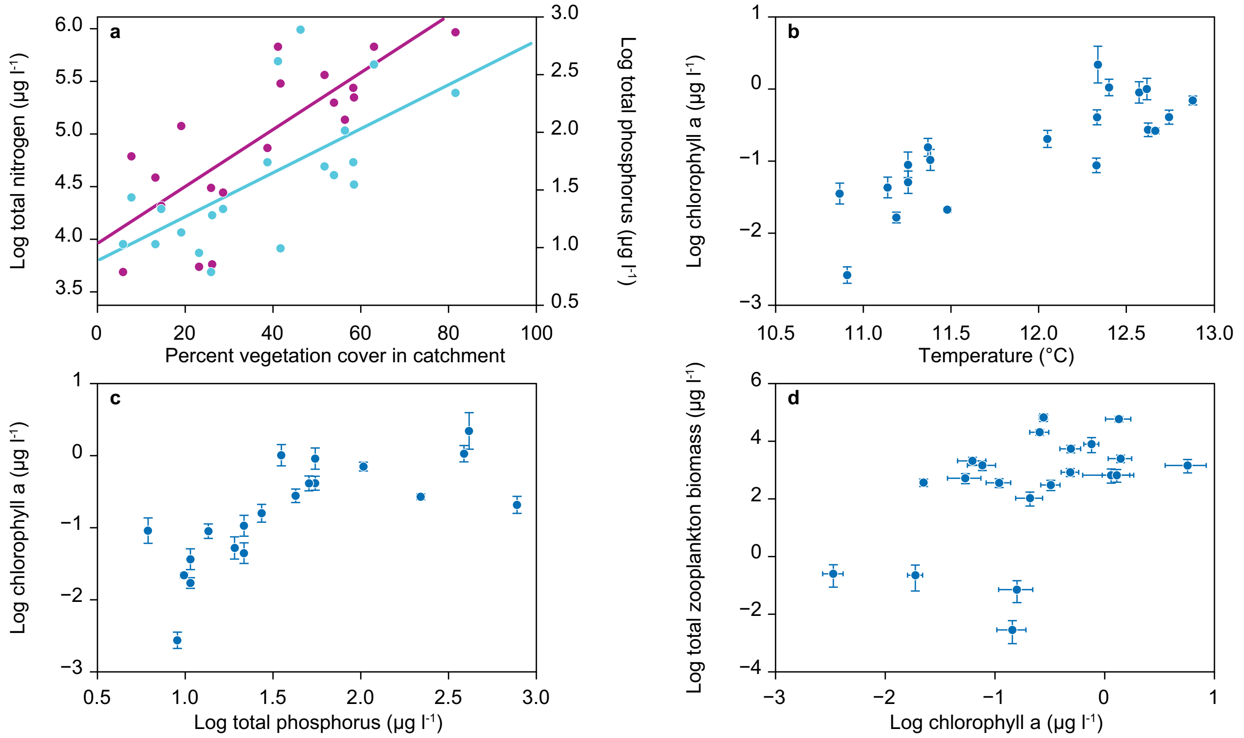


Figure 6.35 Relationship between catchment vegetation cover, water chemistry, phytoplankton and zooplankton biomass in 20 ponds and lakes in the Zackenberg and Daneborg area during July and August. Nutrients and biomasses are log-transformed. a) The nutrient content in the ponds increased with vegetation cover (total nitrogen (purple dots) =3.96+0.027 PctVegetation, $p < 0.0001$, d.f. = 18, total phosphorous (light blue dots) =0.87+0.019 PctVegetation, $p = 0.0017$, d.f. = 18). b) The phytoplankton biomass, measured as chlorophyll a, increased with water temperature (chlorophyll a = -12.82+0.999 °C, $p < 0.0001$, d.f. = 18), and c) with nutrient content (chlorophyll a = -2.18+0.849 µg phosphorous l^{-1}, $p = 0.0004$, d.f. = 18). d) Zooplankton biomass increased with phytoplankton biomass (zooplankton (µg l^{-1}) = 3.46+1.775849 µg chlorophyll a l^{-1}, $p = 0.025$, d.f. = 18). Purple and light blue lines indicate linear regressions of nitrogen and phosphorous, respectively. Bars indicate s.e.m.

between atmospheric forcing, snowpack's/glacier mass-balance, stream flow, water quality and hydrogeomorphology and biotic communities. An understanding of the influence of altered snowmelt, glacier, permafrost and groundwater contributions to Arctic river flow and their effect on biotic communities is essential in the context of increased climatic variability. Moreover, high climatic sensitivity and low human perturbation makes Arctic river basins vital indicator systems for identifying early signals of, and subtle shifts in, hydrological and ecological response to climate change. Changes in water source contributions (deglaciation, reduced snowpack extent, greater rainfall: snow etc.) and habitat conditions will be a major driver of shifts in the biodiversity of Arctic stream benthic communities with potential loss of beta diversity. The principal aim of this highly interdisciplinary project is to understand links in the process cascade between water source contributions, physico-chemical habitat and stream biodiversity and, thus, develop tools to assess the vulnerability of Arctic river ecosystems to climate change.

Fieldwork was conducted in a number of river basins near the Zackenberg field station, for three weeks in June/July 2013. The field programme included: 1) measurement of river discharge, electrical conductivity and turbidity, and water column and streambed temperature (to investigate hydrological variability and habitat conditions); 2) collection of water samples for major ions, Si and water stable isotopes analyses (to identify conceptual water sources and their dynamics), 3) conduct field experiments to examine the uptake of nutrients in streams of different water sources and 4) sampling of benthic biotic communities.

Our hypotheses were that: 1) Maximum alpha diversity will occur in streams with 40 to 60 % melt water contribution; 2) Beta diversity will decrease with reduced inputs from melt water, and 3) the highest uptake of nutrients will occur in groundwater fed systems.

We were able to successfully sample a number of streams in the Zackenberg valley and surrounding area for physico-chemical variables and macroinvertebrates

Figure 6.36 Collection of samples. Photo: Anders G. Finstad.

Figure 6.37 Nutrient uptake equipment set up on stream with Zackenberg hunting station in the background. Photo: Catherine Docherty.

Figure 6.38 Setting up equipment on a stream in the Zackenberg Valley. Photo: Alexander Milner.

(figure 6.37). Nutrient uptake experiments were only successfully conducted at four streams, due to the low amount of snowfall the previous winter, it was not possible to sample more streams due to low water levels, however we were able to map and locate suitable streams for a more extensive study to take place in July 2014. A number of Tiny Tag data loggers were left in streams to measure water temperature at a number of sites for the remainder of the open water season (figure 6.38).

Preliminary data shows less diurnal variability in water temperature of ground water streams compared to melt water streams. All data collected are now being analysed and the biological material sorted and identified.

6.20 MIBIPOL: Ecological and evolutionary constraints on microbial biodiversity in lake ecosystems – a bipolar comparison

Elie Verleyen, Pieter Vanormelingen, Dagmar Obbels, Otakar Strunecky, Josef Elster, Annick Wilmotte, Koen Sabbe and Wim Vyverman

During the summer of 2013, microbial mats were sampled in about 80 lakes near Nuuk (West Greenland) and Zackenberg (North-east Greenland). Additional live samples were taken from temporary ponds, small (melt water) streams and seepages. These campaigns were carried out in the framework of the INTERACT project MIBIPOL, which entails collaboration between the universities of Ghent and Liège (Belgium) and the Centre for Polar Ecology (Czech Republic). MIBIPOL aims at comparing and quantifying the differences in the biodiversity and community structure of bacteria, cyanobacteria and micro-eukaryotes in microbial mats from Arctic and Antarctic lakes using state-of-the-art technologies. The underlying rationale of the project is to test the traditional view that because of unlimited dispersal, most polar micro-organisms will display bipolar distributions. This view requires critical revision as there is growing evidence of dispersal limitation and endemism in these organisms. We therefore hypothesize that given the higher connectivity of Arctic regions microbial communities will be relatively diverse,

Figure 6.39 Surface sediment with microbial mat sampled with the UWITEC corer in the lower Zackenberg valley area (August 2013, 74° 30' 56.6" N, 20° 38' 38.0" W). Photo: Pieter Vanormelingen.

while the more isolated Antarctic communities will be species-poor and dominated by endemic species.

We sampled a total of 43 lakes near Nuuk (26 in the Nuuk/Kobbefjord area, 17 from the Kapisillit area), and 36 lakes near Zackenberg (20 in the lower Zackenberg valley area (figures 6.39 and 6.40), 10 around Daneborg and six in the Kap Ehrenberg area). Microbial mats were sampled using a UWITEC corer from deeper parts of the lake and from the littoral zone. In addition, we also took water samples for limnological (pH, conductivity, temperature and dissolved oxygen) and nutrient analyses, and filters (0.22 µm GSWP) for molecular-genetic analysis of the pelagic microbial communities. Live samples were taken to isolate strains and establish cultures. The microbial mat and water samples will be analysed in 2014 using high-throughput sequencing technologies (Illumina MiSeq). In addition, isolates were established that will be used for multigene molecular-phylogenetic and ecophysiological characterization and DNA barcoding. Special attention was paid to some known cryptic species complexes and allegedly bipolar taxa. To date, approximately 40 diatom isolates from each area were established for further study in Ghent University. A few tens of these belong to the *Eunotia bilunaris/flexuosa* species complex, for which we already have molecular data on 15 lineages from warm to cold temperate climates. These were selected for further molecular-phylogenetic characterization. All data will then be compared with results obtained within ongoing Antarctic projects and stored in open access archives.

Figure 6.40 Lake sampling in the lower Zackenberg valley area (August 2013, 74° 30' 24.2" N, 20° 37' 14.6" W). Photo: Pieter Vanormelingen.

6.21 The function of a polynya: Deployment of moorings in Young Sund, NE Greenland

Søren Rysgaard, Igor Dmitrenko, Sergev Kirillov, David Babb, Leif Riemenschneider, Egon Frandsen and Ivali Lennert

This project is studying polynyas. A polynya is an ice-free site in an otherwise ice-covered area. This particular polynya studied is located outside Young Sund in NE Greenland and is maintained by high winds blowing the newly formed sea ice away from the area (figure 6.41). We deployed various moorings covering measurements of current velocities, salinity and temperature conditions throughout the 350 m deep-water column year round. Current velocities, temperature and salinity profilers will make profiles every hour until we get here again in spring. We also deployed mass balance buoys equipped with weather stations, ultrasonic sensors etc. enabling the measurements of weather conditions, snow and ice depth as well as temperatures within the snow and sea ice. Many of the data will be transmitted to satellites and received by our colleagues in warm offices back home. Finally, we brought a newly developed device called the HARP that will be deployed for the first time in the field. It is a device measuring salinity and temperature conditions at high resolution in the sea ice itself. We were lucky with the weather. When we arrived the sea ice was only patchy distributed in the fjord (figure 6.42). Due to dropping air temperatures and calm weather sea ice formed almost everywhere in the fjord - in places up to 25 cm. Further out of the fjord there was still open water though. This enabled us to deploy all equipment in the ice and hopefully it still is around when we go up in the spring to recover it and the data collected (figure 6.43).

6.22 The bridge across the river Zackenberg

Mikkel Tamstorf, Jørgen Skafte and Flemming Tamstorf

Crossing the river Zackenberg has become a lot easier since September 2013. Since the early days of the Zackenberg Research Station crossing of the river Zackenberg during the summer have been quite a bothersome ordeal. Not only was it difficult to bring equipment in the small dingy and take full advantage of the areas on the western side of the valley but at several occasions we have also seen close calls where people have had severe problems with the violent rapids when crossing the river - the last event resulting in a ban for crossing the river with the small dingy. Furthermore, several of

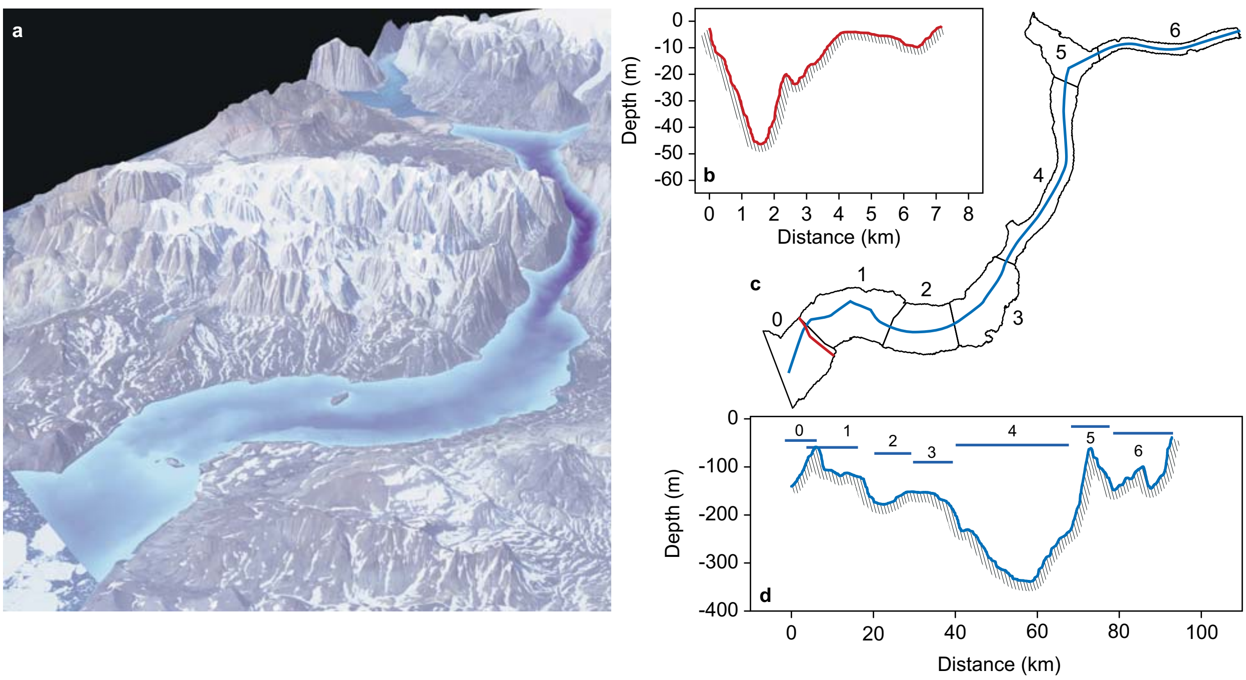


Figure 6.41 Study site – Young Sound, NE Greenland. Photo: Søren Rysgaard.

the more frequent floods have washed away the entire setup for crossing the river, making the manual drainage measurements for Climate and GeoBasis very difficult. For some years it has therefore been a growing wish to get a more permanent and robust solution for accessing the other side of the river.

The idea was, as many ideas are, born over a glass of wine. Was it at all possible to raise money for the purpose of building a bridge in NE-Greenland – far away from the nearest settlement and roads? However, due to the dedicated effort from our fund raiser and generous funding from many contributors it was in 2013 possible to start construction, shipment and building of the new bridge across the river Zackenberg. The funding of more than 5 million DKK was secured through Crown Prince Frederik and Crown Princess Mary's Foundation, the A.P. Møller and Chastine Mc-Kinney Foundation for General Purposes, Aage V. Jensen Charity Foundation, Rene Vejlsgaard's Foundation, Ministry of Climate, Energy and Buildings, Ministry of Environment and Aarhus University as well as private donations from our fund raiser, Flemming Tamstorf. The bridge is projected and drawn by Rambøll, constructed by L&H Rørbyg A/S and build on-site by Bladt Industries.

The construction is a steel bridge with a free span of 45 m. It hangs 3.5 m above normal water level, which is high enough to avoid the highest levels of water during the frequent glacial lake outburst floods from the A.P. Olsen Glacier. The bridge is constructed to stand low temperatures, snow pressure as well as high winds and two full grown persons with heavy equipment standing at the middle of the bridge. It weighs more than 18 tons and is secured in the permafrost with 8 anchor points of 5 cm thick and 5.5 m long steel rods that was drilled into the permafrost before construction. The four anchor points on each side of the river holds the base of each side of the bridge and each base is protected against erosion with boulders secured in a steel netting of the size of 0.5 m high, 10 m wide and 13 m long.

The building of the bridge began in May 2013 with the drilling of holes and placement of the eight anchor points (figure 6.44). This was carried out using the permafrost drill generously made available by University Centre of Svalbard. During July a team of five persons collected all the boulders needed for the erosion protection and helped the logistics with unpacking and airlifting by Twin Otter of all the parts of the 18 ton heavy construction that arrived by ship at Daneborg in the beginning of August. In the beginning of September, a five man team from Bladt Industries and two logisticians from Aarhus University placed the first parts of the bridge of the anchor points and during the following four weeks the bridge was build, now spanning 45 m across the waters of the river Zackenberg (figure 6.45).

The bridge was placed approximately 400 m north of the Zackenberg Research

Figure 6.42 Ivali Lennert on thin ice. Photo: Søren Rysgaard.

Figure 6.43 The Russians are deploying moorings – and they are good at it! Photo: Søren Rysgaard.

Figure 6.44 Drilling boreholes for the anchor points. Photo: Mikkel Tamstorf.

Station as this stretch is currently considered the most stable part of the river. The former crossing just below the station area was heavily eroded during the big flood in 2012 and would cause too many problems not only for the actual construction but also for the ongoing monitoring of drainage patterns etc. The bridge is therefore reached by a 1 km walk along the landing strip and the newly established path across the heath.

Access to the bridge is via the stairs at each end and to avoid handling heavy instruments up the stairs such equipment (up to 150 kg) can be dragged across the river on the small pulley system below the bridge (to be installed in 2014). The hydrological station of ClimateBasis will also be moved to the bridge during 2014 to avoid the frequent damage or loss of equipment during the floods.

Figure 6.45 The bridge was put together on-site by a crew of seven people using mainly hand power. Photo: Jørgen Skafte.

7 Disturbances in the study area

Jannik Hansen

This account covers the period from 23 April to 30 October 2013. For details about the opening and operations of the station, see chapter 8.

7.1 Surface activities in the study area

May – August: The number of 'person-days' (one person in the field one day) spent within the main research area, Zone 1 (table 7.1) was 2240, which is higher than recent years. The 'low impact area' Zone 1b was visited in numbers similar to previous seasons, although more in August than usual. The 'goose protection area', Zone 1c, was visited on very few occasions, during the closed period, 20 June-10 August. Unfortunately, data for use of the areas was unavailable for May.

This season, the use of the all-terrain vehicle (ATV) was mainly along the designated roads to the climate station and the beach at the delta of the river Zackenberg. Twice during May and twice during July were the only times they were in use off the designated road system. However, the use of the ATV at and near the station has become higher since 2007, and is remaining at a high level.

During the early and late part of the season, snowmobiles were used for transportation of equipment and personnel.

Table 7.1 'Person-days' and trips in the terrain with an All-Terrain Vehicle (ATV) allocated to the research zones in the Zackenberg study area June –August 2013. 1c, the "Goose Protection Area" is closed for human traffic from 20 June to 10 August (DOY: 171-222). Trips on roads to the climate station and the delta of the river Zackenberg are not included.

Research zone	May	June	July	Aug	Total
All of 1 (incl. 1a)	141	459	628	1012	2240
1b	N/A	5	27	33	65
1c (20 Jun-10 Aug)		0	8	0	8
Part of zone 1*	N/A	0	70	37	107
2	0	0	4	10	14
ATV-trips	2	0	2	0	4

*The area west of river Aucella

7.2 Aircraft activities in the study area

For details on number of visits by fixed-wing aircrafts and helicopters see chapter 8.

During the 2013 season, the arrival of aircrafts did not make waterfowl fly up from the lakes, ponds and fens nearby. Possibly, geese get accustomed to regular disturbance (cf. Madsen and Boertmann 2008).

7.3 Discharges

Water closets in the residential house were in use from late April onwards, while the separate toilet building opened early June. From here, all toilet waste was grinded in an electrical mill and led into the river.

Likewise, solid, biodegradable kitchen waste was run through a grinder mill, and into the river. The mill was in use until the end of the season.

The total amount of untreated waste-water (from kitchen, showers, sinks and laundry machine) equalled approximately 2448 'person-days' during May-August, which is very high compared to previous years. The gradual phase-out of perfumed and non-biodegradable detergent, soap, dishwashing liquid etc. is continuing. More environmentally friendly products are being taken in use.

Combustible waste (paper, cardboard, wood etc.) was burned at the station. For management of other waste, please see chapter 8.

7.4 Manipulative research projects

The coordinates and extent of all manipulation sites mentioned below are registered with BioBasis Zackenberg.

For the tenth consecutive season, shade, snowmelt and temperature was manipulated at two sites, each with 25 plots (see Jensen 2012).

Five exclosures were set up in 2010 to study the effect of musk oxen grazing on vegetation and related ecological effects (see section 6.8).

7.5 Take of organisms and other samples

A herbivore-plant-soil interactions study collected four samples of soil including the vegetation within the monolith, at each of two sites (see section 6.8).

The 'Interactions 2011-2014' project collected four abandoned dunlin eggs. This project also collected the following: Eight blood samples of 20 µl from adult and 16 samples of 10 µl from chicks of dunlin, and six 20 µl blood samples from adult long-tailed skuas (at Zackenberg, this project is run by BioBasis).

During the 2013 season, 22 276 land arthropods were collected as part of the BioBasis programme (see chapter 4).

For a decomposition project, deposited leaf litter was moved from five 20×20 cm plots to five other 20×20 cm plots (see section 6.9).

Twenty blood samples of 80 µl were collected from adult and 56 of 10 µl from chicks of sanderlings for a parentage and breeding strategy project. In addition, this project collected nine eggs that had failed to hatch (see section 6.16).

Tissue samples were collected from a number of animal species for the BioBasis DNA bank (see table 4.28, chapter 4).

For the "High Arctic Food Web", approximately 108 500 arthropods were caught in seven malaise traps. Table 7.2 shows the number of individual arthropods caught by different methods at different sites (some of which are connected to other projects as well).

For all trapping methods, including the malaise trappings, a total of 118 825 arthropods were caught by this project. All by caught insects were released unharmed. Also, 828 mountain avens were sampled (see table 7.2 and section 6.15).

A project on ecological and evolutionary constraints of microbial biodiversity in lake ecosystems, took 12 samples of microbial communities from an area (approximately 25 cm²) at the bottom and littoral zone of lakes. Additionally 106 water samples (250 ml in each lake) were taken in lakes both within and outside the general Zackenberg study area (see section 6.20).

For a project evaluating SAR data for Arctic tundra landscapes, three 10 cm² vegetation plots were harvested at 20 different sites on different points in time (see section 6.12).

Another project looking at bryophyte biodiversity and importance as herbivore diet collected 285 samples of bryophytes, and 50 samples of fresh faecal matter, mainly from barnacle geese and musk oxen (see section 6.11).

The project 'Nutrient fluxes and biotic communities in Arctic rivers' collected 28 water samples (see section 6.19).

Samples were collected from 16 lakes and ponds in the project 'Trophic interactions, temperature and greening in a changing climate' (see section 6.18).

Table 7.2 The number of plants sampled and arthropods caught by the 'High Arctic Food Web' and related projects in Zackenberg 2013. Courtesy of Kristiina Visakorpi and Tomas Roslin.

Harvest type	Type of individuals	No. individuals/site	No. of sites	Total no. individuals caught
Enclosure	Arthropods	200	31	6200
Enclosure	*Dryas octopetala*	15	31	465
Enclosure	*Dryas octopetala*	5	44	220
Transect	Arthropods	1100	3	3300
Pitfall field	Flying insects, mainly *Diptera*	250	2	500
Spider catching pitfall field	*Pardosa glacialis*	100	1	100
Malaise trap	Flying insects, mainly *Diptera*	15.500	7	108500
Pilot flower	*Dryas octopetala*	1	18	18
Pollinator exclusion flower	*Dryas octopetala*	1	125	125
Muskox enclosure	Spiders	15	15	225

A coordinated PhD project/course on permafrost collected 106 soil samples from different plots. Furthermore, microbial distance decay was studied in 117 samples collected from nine different plots (see section 6.4).

The project 'Structure and function of microbial communities in challenging, polar terrestrial habitats: a pan-Arctic survey' collected 24 rock samples from seven sites (see section 6.6).

In a project trying to forecast and hindcast the effect of climate on Zackenberg flora, 356 vegetation samples and 200 soil samples were collected (see section 6.13).

Seventy-four cyanobacterial mats and 83 stones were collected for the project 'The structure and function of microbial communities in challenging, polar terrestrial habitats: a pan-Arctic survey. For the same project, 19 vegetation samples, 51 soil samples and 21 rocks were collected at other sites (see section 6.7).

Forty-five samples of rock and sediment were collected for the project 'Cross-calibrating dating techniques around Greenland' (see 6.3).

Sixty-five sediment samples were collected for the project 'The impact of permafrost on the stability of sedimentary shores in the Young Sund area' (see section 6.5).

A project, looking at N uptake and permafrost, sampled 10 g soil in 10 cm intervals in 30 plots. The soil samples were exported for analysis. In addition, approximately 2 g of plant matter were removed from each of the 30 plots, in total 60 g plant matter. Furthermore, 30 g soils samples from 50 plots were extracted with water, and 10 g soil exported for analysis. All holes were refilled with soil (see section 6.10).

7.6 Building of the bridge

In autumn 2013, a bridge was being built in order to accommodate the traffic across the river Zackenberg. Several research and monitoring sites are situated west side of the river, and the bridge is making it possible to conduct work at these sites on a more regular basis than before.

Twenty tonnes of bridge material were flown in on 25 flights, and transported (along with the machinery and other equipment that the contractors needed to build and secure the bridge) to the bridge site.

During the period of building, a long spell of rain meant that the otherwise usually dry tundra was very wet. The road from the airstrip into the valley was therefore gathering a lot of water and the heavy use of the ATV (see figure 7.1) with trailer was making a large impact on the road, despite much effort by the logistics to secure the road. In some cases, the ATV had to drive alongside the road to avoid the trailer digging into the wheel tracks and getting stuck. This, in turn, meant that in some places the road widened and water erosion damaged the immediate surroundings of parts of the road.

Also, a new stretch of road was introduced, from the valley to the bridge site. The road was placed on habitat which normally is dry. Due to the unusual circumstances, this road too suffered and was widened more than originally intended.

In 2014, efforts will be made to ensure people walk as little as possible on these widened parts of the roads, hoping the damaged parts will regenerate.

Figure 7.1 Flemming Bach driving the ATV, with trailer loaded with parts for the bridge, along the road on a deteriorating road track. Photo: Laura Helene Rasmussen.

8 Logistics

Henrik Spanggård Munch and Lillian Magelund Jensen

8.1 Use of the station

In 2013, the field season at Zackenberg was from 23 April to 30 October, in total 190 days. During the period, 91 researchers visited the station. Of the 91 scientists, 10 stayed in the research house in Daneborg. They were serviced by 12 logisticians employed by the Department of Bioscience at Aarhus University.

The total number of bed nights during 2013 was 2752. 2521 of the bed nights were spend at Zackenberg (1835 related scientists and two VIP visits, and 686 related to logisticians and personnel for the construction of the bridge across the river Zackenberg). 231 of the bed nights were spend at the research house at Daneborg (154 related to scientists and 77 was related logisticians).

During the season, the station was visited by researchers from 19 countries: Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greenland, Hungary, Italy, Netherland, Norway, Russia, Scotland, Sweden, Switzerland, UK and USA.

8.2 Transportation

During the field season, fixed winged aircrafts (De Havilland DHC-6 Twin Otter) landed 84 times at Zackenberg. Of the 84 landings, 39 landings were related to transport of material for the bridge construction.

8.3 Maintenance

During 2013, no larger maintenance work was carried out at Zackenberg Research Station. The maintenance condition of the station is very good. Besides the normal painting of the houses, we do not expect larger maintenance costs during the year to come.

8.4 Handling of garbage

Non-burnable waste was removed from Zackenberg Research Station by aircraft to Daneborg on the empty return flights during the fuel lifts from Daneborg to Zackenberg and from there the waste was send by ship to Denmark. Non-burnable waste was also removed from the research house at Daneborg and send by ship to Denmark. Approximately 33 m^3 of waste were removed from the station and from the research house.

8.5 Acquisitions

Due to wear of the station's old ARGO (all-terrain vehicle – ATV) a new ARGO was purchased. Furthermore, due to wear of the station's old RIB (boat) a new boat was purchased. The new boat is a 'Polarcirkel Work Boat type' manufactured in Norway. This type of boat is adapted to Arctic areas and has been used in Svalbard for several years.

9 Personnel and visitors

Compiled by Lillian Magelund Jensen

Research Zackenberg

Ulrika Belsing, Research assistant, Department of Physical Geography and Ecosystem Science, Lund University, Sweden (Plant-Soil-Herbivore, 26 June-21 August)

Mette Bendixen, Researcher, Centre for Permafrost, Department of Geosciences and Natural Resource Management, University of Copenhagen, Denmark (Permafrost, 21 August-26 September)

David Binder, Researcher, Department of Climatology, Central Institute for Meteorology and Geodynamics, Austria (Glaciology, 23 April-8 May and 7-21 August)

Geo Boffi, Researcher, Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology, Austria (Glaciology, 23 April-8 May)

Hanne H. Christiansen, Researcher, Arctic Geology, University Centre in Svalbard, Norway and Centre for Permafrost, Department of Geosciences and Natural Resource Management, University of Copenhagen, Denmark (Permafrost, 21 August-5 September)

Torben Røjle Christensen, Researcher, Department of Physical Geography and Ecosystems Science, Lund University, Sweden (GeoBasis, 31 July-7 August)

Kirsten S. Christoffersen, Researcher, Freshwater Biological Laboratory, University of Copenhagen, Denmark (BioBasis and Limnology, 21 August-5 September)

Michele Citterio, GlacioBasis manager, Department of Marine Geology and Glaciology, Geological Survey of Denmark and Greenland, Denmark (Glaciology, 23 April-8 May 2013)

Jesse Conklin, Research assistant, Animal Ecology Group, University of Groningen, the Netherlands (Ornithology, 11 June-14 August)

Malin Ek, Researcher assistant, Department of Arctic and Marine Biology, Arctic University of Norway, Norway (Arthropod community ecology, 10-24 July)

Bo Elberling, Researcher, Arctic Geology, University Centre in Svalbard, Norway and Centre for Permafrost, Department of Geosciences and Natural Resource Management, University of Copenhagen, Denmark (Permafrost, 21 August-5 September)

Catherine Docherty, Researcher, School of Geography, Earth and Environmental Sciences, University of Birmingham, UK (Hydroecology, 26 June -17 July)

Julie Maria Falk, Researcher, Department of Physical Geography and Ecosystems Science, Lund University, Sweden (Plant-Soil-Herbivore, 26 June-3 July and 7-21 August)

Wesley R. Farnsworth, Researcher, Arctic Geology, University Centre in Svalbard, Norway (Permafrost, 21 August-5 September)

Anders Gravbøl Finstad, Researcher, Norwegian Institute for Nature Research, Norway (Limnology, 17 July-14 August)

Graham L. Gilbert, Researcher, Arctic Geology, University Centre in Svalbard and Department of Geosciences, University of Oslo, Norway (Permafrost, 21 August-5 September)

Kjersti Gisnås, Researcher, Department of Geosciences, University of Oslo, Norway (Permafrost, 21 August-5 September)

Carsten Grøndahl, Researcher, Copenhagen Zoo, Denmark (Musk ox GPS, 3-21 October)

David Hannah, Researcher, School of Geography, Earth and Environmental Sciences, University of Birmingham, UK (Hydroecology, 26 June-5 July)

Birger Ulf Hansen, Researcher, Department of Geosciences and Natural Resource Management, University of Copenhagen, Denmark (GeoBasis, 16-30 August)

Jannik Hansen, Research assistant, Department of Bioscience, Aarhus University, Denmark (BioBasis, 29 May-7 August)
Lars Holst Hansen, Research assistant, Department of Bioscience, Aarhus University, Denmark (BioBasis, 26 June-21 October)
Ditte Katrine Hendrichsen, Researcher, Norwegian Institute for Nature Research, Norway (Limnology, 17 July-14 August)
Jakob Humaidan, Research assistant, Department of Bioscience, Aarhus University, Denmark (BioBasis, 10 July-26 August)
Stefanie Härtel, Researcher, Arctic Geology, University Centre in Svalbard, Norway and Centre for Permafrost, Department of Geosciences and Natural Resource Management, University of Copenhagen, Denmark (Permafrost, 14 August-5 September)
Bernard Hynek, Researcher, Department of Climatology, Central Institute for Meteorology and Geodynamics, Austria (Glaciology, 7-21 August)
Vincent Jomelli, Researcher, Laboratoire de Géographie Physique, Centre National de la Recherche Scientifique, France (Dating techniques 17-31 July)
Hans (J.D) Kruijer, Researcher, Naturalis Biodiversity Centre, Leiden University, The Netherlands (Bryophytes, 10-24 July)
Ondrej Komarek, Researcher, Institute of Microbiology, Department of Phototrophic Microorganisms, Academy of Sciences of the Czech Republic, Czech Republic (Microbial communities, 3-17 July)
Aart Kroon, Researcher, Centre for Permafrost, Department of Geosciences and Natural Resource Management, University of Copenhagen, Denmark (Permafrost, 28 August-26 September)
Frida Lindwall, Research assistant, Department of Biology, University of Copenhagen, Denmark (Terrestrial ecology, 17 July-7 August)
Mikhail Mastepanov, Researcher, Department of Physical Geography and Ecosystems Science, Lund University, Sweden (GeoBasis, 3-31 July)
Anders Michelsen, Researcher, Department of Biology, University of Copenhagen, Denmark (Terrestrial Ecology, 14-21 August)
Alexander Milner, Researcher, School of Geography, Earth and Environmental Sciences, University of Birmingham, UK (Hydroecology, 26 June-5 July)
Jesper B. Mosbacher, Research assistant, Department of Bioscience, Aarhus University, Denmark (Musk ox GPS, 3-21 October)
Maria Rask Mylius, Researcher, Department of Geosciences and Natural Resource Management, University of Copenhagen, Denmark (GeoBasis, 23 April-26 June and 3-30 October)
Cecilie S. Nielsen, Researcher, Centre for Permafrost, Department of Geosciences and Natural Resource Management, University of Copenhagen, Denmark (Permafrost, 21 August-5 September)
Palle Smedegaard Nielsen, Research assistant, Department of Bioscience, Aarhus University, Denmark (BioBasis, 8 May-26 June)
Erland Birkeland Nilsen, Researcher, Norwegian Institute for Nature Research, Norway (Limnology, 17-31 July)
Juri Palmtag, Researcher, Department of Physical Geography and Quaternary Geology, University of Stockholm, Sweden (Permafrost, 21 August-5 September)
Loïc Pellissier, Researcher, Unit of Ecology and Evolution, Université de Fribourg, Switzerland (Vegetation communities, 7-31 July)
Lau Gede Petersen, Research assistant, Department of Geosciences and Natural Resource Management, University of Copenhagen, Denmark (GeoBasis, 31 July-4 September)
Anders Rasmussen, Technician, Department of Bioscience, Aarhus University, Denmark (GeoBasis, 7-21 August)
Laura Helene Rasmussen, Research assistant, Department of Geosciences and Natural Resource Management, University of Copenhagen, Denmark (GeoBasis, 3-31 July and 28 August-3 October)
Jeroen Reneerkens, Researcher, Animal Ecology Group, University of Groningen, the Netherlands (Ornithology 11 June-14 August)
Vincent Rinterknecht, Researcher, Department of Earth and Environmental Sciences, University of St Andrews, UK (Dating techniques, 17-31 July)
Tomas Roslin, Researcher, Department of Agricultural Sciences, University of Helsinki, Finland (Arthropod community ecology, 12 June-3 July 2013)
Suvi M. Saarnio, Researcher, Department of Geography, University of Oulu, Finland (Permafrost, 21 August-5 September)

Niels Martin Schmidt, Scientific leader of Zackenberg Research Station and BioBasis manager, Department of Bioscience, Aarhus University, Denmark (BioBasis and Musk ox GPS, 3-21 October)
Caroline Ernberg Simonsen, Research assistant, Department of Bioscience, Aarhus University, Denmark (Vegetation communities, 16 July-7 August)
Kirstine Skov, Research assistant, Department of Physical Geography and Ecosystems Science, Lund University, Sweden (GeoBasis, 12 June-21 August)
Jennifer Sobiech-Wolf, Researcher, Helmholtz Center for Polar and Marine Research, Alfred Wegener Institute, Germany (Remote sensing, 24 July-21 August)
Michael Stech, Researcher, Naturalis Biodiversity Centre, Leiden University, The Netherlands (Bryophytes, 10-24 July)
Mikkel Stelvig, Researcher, Copenhagen Zoo, Denmark (Musk ox GPS, 3-21 October)
Katja Sterflinger, Researcher, VIBT-Extremophile Centre, University of Natural Resources and Life Sciences, Vienna, Austria (Microbial communities, 3-17 July
Lærke Stewart, Researcher, Department of Bioscience, Aarhus University, Denmark (Vegetation communities, 9 July-7 August)
Marek Stibal, Research assistant, Department of Geochemistry, Geological Survey of Denmark and Greenland, Denmark (Glacier surface microbiology, 23 April-8 May 2013)
Otakar Strunecky, Researcher, Centre for Polar Ecology, Department of Ecosystem Biology, University of South Bohemia, Czech Republic (Limnology, 14 August-5 September)
Lena Ström, Researcher, Department of Physical Geography and Ecosystems Science, Lund University, Sweden (Plant-Soil-Herbivore, 14-21 August)
Sarah Hagel Svendsen, Research assistant, Department of Biology, University of Copenhagen, Denmark (Terrestrial ecology, 3-17 July and 14-28 August)
Mikkel P. Tamstorf, GeoBasis manager, Department of Bioscience, Aarhus University, Denmark (GeoBasis, 8-29 May and 19-30 October)
Pieter Vanormelingen, Researcher, Laboratory of Protistology and Aquatic Ecology, Department of Biology, Ghent University, Belgium (Limnology, 14 August-5 September)
Gergely Várkonyi, Researcher, Finnish Environment Institute, Friendship Park Research Centre, Finland (Arthropod community ecology, 10-24 July 2013)
Stefano Ventura, Researcher, Institute of Ecosystem Study, CNR, Italy (Microbial communities, 3-17 July)
Kristiina Visakorpi, Research assistant, Department of Biosciences, University of Helsinki, Finland (Arthropod community ecology, 12 June-14 August)
Niels Weiss, Researcher, Departments of Physical Geography and Quaternary Geology, University of Stockholm, Sweden (Permafrost, 21 August-5 September)
Andreas Westergaard-Nielsen, Researcher, Centre for Permafrost and Department of Geosciences and Natural Resource Management, University of Copenhagen, Denmark (GeoBasis, 17-31 July and Permafrost 21 August-5 September)
Georg Sebastian Westermann, Researcher, Department of Geosciences, University of Oslo, Norway (21-28 August)

Research Daneborg

David Babb, Researcher, Centre for Earth Observation Science, Department of Environment and Geography, University of Manitoba, Canada (Polynyas, 21-30 October)
Igor Dmitrenko, Researcher, Centre for Earth Observation Science, Department of Environment and Geography, University of Manitoba, Canada (Polynyas, 21-30 October)
Egon Frandsen, Technician, Arctic Research Centre, Aarhus University, Denmark (MarineBasis and Polynyas, 31 July-21 August and 21-30 October)
Thomas Juul-Pedersen, MarineBasis manager, Greenland Institute of Natural Resources, Greenland (MarineBasis, 31 July-21 August)
Sergev Kirillov, Researcher, Centre for Earth Observation Science, Department of Environment and Geography, University of Manitoba, Canada (Polynyas 21-30 October)
Ivali Lennart, Technician, Greenland Institute of Natural Resources, Greenland (MarineBasis and Polynyas, 31 July-21 August and 21-30 October)
Leif Riemenschneider, Researcher, Max Planck Institute for Meteorology, Germany (Polynyas, 21-30 October)

Søren Rysgaard, Researcher, Centre for Earth Observation Science, Department of Environment and Geography, University of Manitoba, Canada and Arctic Research Centre, Aarhus University, Denmark (Polynyas, 21-30 October)

Logistics Zackenberg and Daneborg

Jonas Møller Andersen, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (24 July-5 September)
Jacob Eriksen, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (24 July-21 August)
Jakob Fledelius, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (24 July-21 August)
Henrik Krohn Hansen, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (8-29 May)
Helle Hildebrand, Cook, Department of Bioscience, Aarhus University, Denmark (24 July-5 September)
Henrik Engel Kjøller, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (24 July-21 August)
Søren Kyed, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (17 July-5 September)
Jørn Ladegaard, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (5 September-3 October)
Dina Laursen, Cook, Department of Bioscience, Aarhus University, Denmark (29 May-24 July)
Kenny P. Madsen, Logistics coordinator, Department of Bioscience, Aarhus University, Denmark (29 May-12 June and 31 July-26 September)
Henrik Spanggård Munch, Logistics manager, Department of Bioscience, Aarhus University, Denmark (29 May-3 July, 31 July-28 August and 3-30 October)
Paw Møller, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (24 July-21 August)
Klaus Winther Rasmussen, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (31 July-21 August)
Lone Riis, Cook, Department of Bioscience, Aarhus University, Denmark (5-27 September)
Kim Simonsen, Logistics assistant, Department of Bioscience, Aarhus University, Denmark (12 June-24 July)
Jørgen Skafte, Logistics coordinator, Department of Bioscience, Aarhus University, Denmark (23 April-29 May, 3-31 July and 21 August-3 October)

VIP visit (24-27 June)

HRH Crown Prince Frederik, Amalienborg, Denmark
Anders Correll, Press manager, Aarhus University, Denmark
Peter Bondo Christensen, Senior Researcher, Aarhus University, Denmark
Karen Agnete Harild, Secretary, Ministry of Higher Education and Science, Denmark
Lauritz B. Holm-Nielsen, Rector, Aarhus University, Denmark
Kim Jørgensen, Head of Department, Ministry of Defence, Denmark
Lars Erik Kann-Rasmussen, Chair of the Board, Villum Foundation, Denmark
Mikael Kristensen, Permanent Secretary, Ministry of Education, Ecclesiastical Affairs, Culture and Gender Equality, Greenland
Brian Bech Nielsen, Dean, Aarhus University, Denmark
Nick Nielsen, Minister of Education, Ecclesiastical Affairs, Culture and Gender Equality, Greenland
Klaus Nygaard, Director, Institute of Natural Resources, Greenland
Kjeld Juel Petersen, Director, Villum Foundation, Denmark
Morten Rasch, Senior Advisor, Aarhus University, Denmark
Søren Rysgaard, Director of Arctic Research Centre, Aarhus University, Denmark
Niels Martin Schmidt, Scientific Leader of Zackenberg Research Station, Aarhus University, Denmark
Christian Schønau, Lord Chamberlain, Amalienborg, Denmark
Henrik Skov, Senior Researcher, Aarhus University, Denmark
Leif Skov, Chair of the Board, Aage V. Jensen Charity Foundation, Denmark
Uffe Toudal, Permanent Secretary, Ministry of Higher Education and Science, Denmark
Two body guards from the Danish Security and Intelligence Service, Denmark
Morten Østergaard, Minister of Higher Education and Science, Denmark

VIP visit (20-21 August)

Christina Bruun Andersen, Secretary, Ministry of Climate, Energy and Building, Denmark
Thomas Egebo, Permanent Secretary, Ministry of Climate, Energy and Building, Denmark
Steffen Kretz, Journalist, Danish Broadcasting Corporation (DR), Denmark

Martin Lidegaard, Minister of Climate, Energy and Building, Denmark
Miiti Lynge, Minister of Environment and Nature, Greenland
Pernille Møller, Head of Office, Ministry of Environment and Nature, Greenland
Søren Stach Nielsen, Permanent Secretary, Ministry of Environment and Nature, Greenland
Morten Skovgård Olsen, Head of Section, Danish Energy Agency, Denmark
Michael Pedersen, Head of Department, Ministry of Environment and Nature, Greenland
José Ramanamihantatsoarana, Camera man, Danish Broadcasting Corporation (DR), Denmark
Niels Martin Schmidt, Scientific leader of Zackenberg Research Station, Aarhus University, Denmark
Rikke Thoning, Head of Office, Ministry of Climate, Energy and Building, Denmark

Bridge constructors (5-26 September)

Flemming Bach, Bladt Industries
Konrad Bøknæs, Bladt Industries
Martin Højholt, Bladt Industries
Flemming Nielsen, Bladt Industries
Søren Overgård, Bladt Industries

Further contributors to the annual report

Jakob Abermann, Asiaq – Greenland Survey, Greenland
Andreas Ahlstrøm, Department of Marine Geology and Glaciology, Geological Survey of Denmark and Greenland, Denmark
Luigi D'Acqui, Institute of Ecosystem Study, CNR, Italy
Daan Blok, Centre for Permafrost, University of Copenhagen, Denmark
Roberto De Philippis, Department of Agricultural Biotechnology, University of Firenze, Italy
Josef Elster, Centre for Polar Ecology, Department of Ecosystem Biology, University of South Bohemia, Czech Republic
Peter Hambäck, Department of Ecology, Environment and Plant Sciences, Stockholm University, Sweden
Per Hangaard, Asiaq – Greenland Survey, Greenland
Bess Hardwick, Department of Agricultural Sciences, University of Helsinki, Finland
Signe Hillerup Larsen, Department of Marine Geology and Glaciology, Geological Survey of Denmark and Greenland, Denmark
Magnus Lund, Department of Bioscience, Aarhus University, Denmark
Andreas Noack, VIBT-Extremophile Centre, University of Natural Resources and Life Sciences, Austria
Dagmar Obbels, Laboratory of Protistology and Aquatic Ecology, Department of Biology, Ghent University, Belgium
Dorthe Petersen, Asiaq – Greenland Survey, Greenland
Filippo Calí Quaglia, Department of Marine Geology and Glaciology, Geological Survey of Denmark and Greenland, Denmark and Universitá degli Studi di Torino, Italy
Riikka Rinnan, Department of Biology, University of Copenhagen, Denmark
Koen Sabbe, Laboratory of Protistology and Aquatic Ecology, Department of Biology, Ghent University, Belgium
Natasa Saric, VIBT-Extremophile Centre, University of Natural Resources and Life Sciences, Austria
Wolfgang Schöner, Department of Climatology, Central Institute for Meteorology and Geodynamics, Austria
Charlotte Sigsgaard, Department of Geosciences and Natural Resource Management, University of Copenhagen, Denmark
Majbritt Westring Sørensen, Asiaq – Greenland Survey, Greenland
Flemming Tamstorf, Fundraiser, Denmark
Geert Verhoeven, Institute for Geodesy and Photogrammetry, ETH Zurich, Switzerland
Elie Verleyen, Laboratory of Protistology and Aquatic Ecology, Department of Biology, Ghent University, Belgium
Christian Voitl, VIBT-Extremophile Centre, University of Natural Resources and Life Sciences Vienna, Austria
Wim Vyverman, Laboratory of Protistology and Aquatic Ecology, Department of Biology, Ghent University, Belgium
Gernot Weyss, Department of Climatology, Central Institute for Meteorology and Geodynamics, Austria
Annick Wilmotte, Centre for Protein Engineering, University of Liège, Belgium
Helena Wirta, Department of Agricultural Sciences, University of Helsinki, Finland

10 Publications

Compiled by Lillian Magelund Jensen

Scientific publications

Avery, M., Roslin, T., Hopkins, T., Kaartinen, R. and Várkonyi, G. 2013. Climate, phenology and invertebrate population ecology in Greenland. In Jensen, L.M. et al. (eds.). Nuuk Ecological Research Operations, 6th Annual Report, 2012. Aarhus University, DCE – Danish Centre for Environment and Energy. 92 pp.

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Appendix

Day of Year

Regular years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1	32	60	91	121	152	182	213	244	274	305	335
2	2	33	61	92	122	153	183	214	245	275	306	336
3	3	34	62	93	123	154	184	215	246	276	307	337
4	4	35	63	94	124	155	185	216	247	277	308	338
5	5	36	64	95	125	156	186	217	248	278	309	339
6	6	37	65	96	126	157	187	218	249	279	310	340
7	7	38	66	97	127	158	188	219	250	280	311	341
8	8	39	67	98	128	159	189	220	251	281	312	342
9	9	40	68	99	129	160	190	221	252	282	313	343
10	10	41	69	100	130	161	191	222	253	283	314	344
11	11	42	70	101	131	162	192	223	254	284	315	345
12	12	43	71	102	132	163	193	224	255	285	316	346
13	13	44	72	103	133	164	194	225	256	286	317	347
14	14	45	73	104	134	165	195	226	257	287	318	348
15	15	46	74	105	135	166	196	227	258	288	319	349
16	16	47	75	106	136	167	197	228	259	289	320	350
17	17	48	76	107	137	168	198	229	260	290	321	351
18	18	49	77	108	138	169	199	230	261	291	322	352
19	19	50	78	109	139	170	200	231	262	292	323	353
20	20	51	79	110	140	171	201	232	263	293	324	354
21	21	52	80	111	141	172	202	233	264	294	325	355
22	22	53	81	112	142	173	203	234	265	295	326	356
23	23	54	82	113	143	174	204	235	266	296	327	357
24	24	55	83	114	144	175	205	236	267	297	328	358
25	25	56	84	115	145	176	206	237	268	298	329	359
26	26	57	85	116	146	177	207	238	269	299	330	360
27	27	58	86	117	147	178	208	239	270	300	331	361
28	28	59	87	118	148	179	209	240	271	301	332	362
29	29		88	119	149	180	210	241	272	302	333	363
30	30		89	120	150	181	211	242	273	303	334	364
31	31		90		151		212	243		304		365

Day of Year

Leap years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1	32	61	92	122	153	183	214	245	275	306	336
2	2	33	62	93	123	154	184	215	246	276	307	337
3	3	34	63	94	124	155	185	216	247	277	308	338
4	4	35	64	95	125	156	186	217	248	278	309	339
5	5	36	65	96	126	157	187	218	249	279	310	340
6	6	37	66	97	127	158	188	219	250	280	311	341
7	7	38	67	98	128	159	189	220	251	281	312	342
8	8	39	68	99	129	160	190	221	252	282	313	343
9	9	40	69	100	130	161	191	222	253	283	314	344
10	10	41	70	101	131	162	192	223	254	284	315	345
11	11	42	71	102	132	163	193	224	255	285	316	346
12	12	43	72	103	133	164	194	225	256	286	317	347
13	13	44	73	104	134	165	195	226	257	287	318	348
14	14	45	74	105	135	166	196	227	258	288	319	349
15	15	46	75	106	136	167	197	228	259	289	320	350
16	16	47	76	107	137	168	198	229	260	290	321	351
17	17	48	77	108	138	169	199	230	261	291	322	352
18	18	49	78	109	139	170	200	231	262	292	323	353
19	19	50	79	110	140	171	201	232	263	293	324	354
20	20	51	80	111	141	172	202	233	264	294	325	355
21	21	52	81	112	142	173	203	234	265	295	326	356
22	22	53	82	113	143	174	204	235	266	296	327	357
23	23	54	83	114	144	175	205	236	267	297	328	358
24	24	55	84	115	145	176	206	237	268	298	329	359
25	25	56	85	116	146	177	207	238	269	299	330	360
26	26	57	86	117	147	178	208	239	270	300	331	361
27	27	58	87	118	148	179	209	240	271	301	332	362
28	28	59	88	119	149	180	210	241	272	302	333	363
29	29	60	89	120	150	181	211	242	273	303	334	364
30	30		90	121	151	182	212	243	274	304	335	365
31	31		91		152		213	244		305		366